Package 'ArvindSt'

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Title Five Novel Stochastic Regression Models with Arvind-Distributed Errors and Effects

Version 1.1.0

Description Implements the 'Arvind' distribution and five novel stochastic regression models that replace the traditional Gaussian error assumption with 'Arvind'-distributed errors. The 'Arvind' distribution is a flexible single-parameter continuous distribution on the positive real line characterised by a polynomial numerator with Gaussian-type decay. The package provides complete distribution functions (darvind(), parvind(), qarvind(), rarvind()), maximum likelihood estimation via fit_arvind_mle(), and five model-fitting routines: Random Walk on Coefficients via fit_rw1(), Time-Varying Coefficient Linear Model via fit_tvlm(), Simulation-Extrapolation via fit_simex(), Mixed-Effects Regression via fit_mixed(), and Regime-Switching Hidden Markov Model via fit_hmm(). Additionally provides Monte Carlo forecasting with prediction intervals via forecast_arvind(), comprehensive goodness-of-fit diagnostics (21 metrics and 25 plots) via diagnostics_arvind() and plot_arvind(), k-fold and rolling-window cross-validation via cv_arvind(), and unified model comparison via summary_arvind(). For more details see Pandey, Singh, Tyagi, and Tyagi (2024), ``Modelling climate, COVID-19, and reliability data: A new continuous lifetime model under different methods of estimation", 'Statistics and Applications', 22(2).

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Author Shikhar Tyagi [aut, cre] (ORCID:
<https://orcid.org/0000-0003-1606-0844>),
Arvind Pandey [aut]

Maintainer Shikhar Tyagi <shikhar1093tyagi@gmail.com>

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Contents

`arvind_mean_fn` *Mean of the Arvind Distribution*

Description

Computes the theoretical mean of the Arvind distribution with parameter `theta` by numerical integration.

Usage

```
arvind_mean_fn(theta)
```

Arguments

`theta`	positive numeric scalar; the distribution parameter.

Value

A numeric scalar giving the theoretical mean, or NA if integration fails.

Examples

```
arvind_mean_fn(1)
arvind_mean_fn(2)
```

`arvind_var_fn` *Variance of the Arvind Distribution*

Description

Computes the theoretical variance of the Arvind distribution with parameter `theta` by numerical integration.

Usage

```
arvind_var_fn(theta)
```

Arguments

`theta`	positive numeric scalar; the distribution parameter.

Value

A numeric scalar giving the theoretical variance, or NA if integration fails.

Examples

```
arvind_var_fn(1)
arvind_var_fn(2)
```

`cv_arvind` *K-Fold and Rolling-Window Cross-Validation*

Description

Performs k-fold cross-validation and optionally rolling-window (expanding-window) cross-validation for an `ArvindFit` model.

Usage

```
cv_arvind(fit, k_folds = 5, rolling = TRUE, n0_frac = 0.5, seed = 42)
```

Arguments

fit	an object of class "ArvindFit".
k_folds	integer; number of cross-validation folds (default: 5).
rolling	logical; if TRUE (default), also performs rolling-window cross-validation.
n0_frac	numeric; fraction of data used as initial training window for rolling CV (default: 0.5).
seed	integer; random seed for reproducibility (default: 42).

Value

A list with components:

cv_rmse numeric vector of length k_folds; per-fold RMSE.

cv_mae numeric vector of length k_folds; per-fold MAE.

mean_cv_rmse numeric; average k-fold RMSE.

mean_cv_mae numeric; average k-fold MAE.

roll_rmse numeric; rolling-window RMSE (or NA).

See Also

diagnostics_arvind(), forecast_arvind()

Examples

```
dat <- simulate_arvind_data(n = 50, seed = 1)
m1 <- fit_rw1(Y ~ X1 + X2 + X3, dat, seed = 42)
cv <- cv_arvind(m1, k_folds = 3, rolling = FALSE, seed = 42)
cv$mean_cv_rmse
```

---

darvind *Arvind Distribution Density Function*

Description

Computes the probability density function (PDF) of the Arvind distribution.

Usage

```
darvind(x, theta, log = FALSE)
```

Arguments

x	numeric vector of quantiles.
theta	positive numeric scalar; the distribution parameter.
log	logical; if TRUE, log-density is returned. Default FALSE.

Details

The Arvind distribution with parameter $\theta > 0$ has PDF

$$f(x;\theta) = \frac{\theta(1 + 2x + 2\theta x^2)}{(1+\theta x)^2} \exp(-\theta x^2), \quad x > 0.$$

Value

A numeric vector of density values (or log-density values when `log = TRUE`).

Examples

```
# Evaluate the PDF at several points
darvind(c(0.5, 1, 2), theta = 1)

# Log-density
darvind(1, theta = 2, log = TRUE)

# Returns 0 for x <= 0
darvind(-1, theta = 1)
```

`diagnostics_arvind` *Goodness-of-Fit Diagnostics for Arvind Models*

Description

Computes 21 goodness-of-fit metrics for any fitted `ArvindFit` object, including MSE, RMSE, MAE, MAPE, R-squared, AIC, BIC, Kolmogorov-Smirnov test, Anderson-Darling statistic, and more.

Usage

```
diagnostics_arvind(fit)
```

Arguments

`fit`	an object of class `"ArvindFit"` returned by any of the model-fitting functions.

Details

The following metrics are computed:

Model character; the model type.

MSE Mean Squared Error.

RMSE Root Mean Squared Error.

MAE Mean Absolute Error.

MAPE Mean Absolute Percentage Error.

R2 R-squared.

AdjR2 Adjusted R-squared.

AIC Akaike Information Criterion.

AICc Corrected AIC.

BIC Bayesian Information Criterion.

LogLik Log-likelihood at the MLE.

Bias Mean residual.

MASE Mean Absolute Scaled Error.

DW Durbin-Watson statistic.

LjungBox_stat Ljung-Box test statistic.

LjungBox_p Ljung-Box p-value.

Theta Estimated Arvind parameter.

KS_stat Kolmogorov-Smirnov test statistic.

KS_pvalue Kolmogorov-Smirnov p-value.

AD_stat Anderson-Darling test statistic.

CvM_stat Cramer-von Mises test statistic.

Value

A data frame with one row and 21 columns of diagnostics metrics. See Details for the full list.

Examples

```
dat <- simulate_arvind_data(n = 50, seed = 1)
m1 <- fit_rw1(Y ~ X1 + X2 + X3, dat, seed = 42)
diagnostics_arvind(m1)
```

`fit_arvind_mle` *Maximum Likelihood Estimation for the Arvind Distribution*

Description

Fits the Arvind distribution to a vector of positive observations by maximum likelihood. Optimisation is performed on the log-scale via the Brent method.

Usage

```
fit_arvind_mle(e_pos)
```

Arguments

`e_pos`	numeric vector of strictly positive observations.

Value

A list with components:

theta numeric; the MLE of theta.

negloglik numeric; the minimised negative log-likelihood.

Examples

```
set.seed(42)
x <- rarvind(200, theta = 2)
fit_arvind_mle(x)
```

`fit_hmm` *Fit Regime-Switching Regression (HMM)*

Description

Fits a hidden Markov model with state-dependent coefficients and Arvind-distributed errors. The EM algorithm with forward-backward recursions is used for parameter estimation, and the Viterbi algorithm decodes the most likely state sequence.

Usage

```
fit_hmm(formula, data, nstates = 2, seed = 42, maxiter = 100, tol = 1e-6)
```

Arguments

`formula`	an object of class `formula`.
`data`	a data frame containing the variables in the formula.
`nstates`	integer; number of hidden states (default: 2).
`seed`	integer; random seed for reproducibility (default: 42).
`maxiter`	integer; maximum EM iterations (default: 100).
`tol`	numeric; convergence tolerance (default: 1e-6).

Value

An object of class `"ArvindFit"`, a list containing the same standard fields as `fit_rw1()`, plus:

nstates integer; number of hidden states.

states integer vector; Viterbi-decoded state sequence.

trans_probs matrix; estimated transition probability matrix.

state_betas list of numeric vectors; state-specific coefficients.

state_sigmas numeric vector; state-specific standard deviations.

See Also

diagnostics_arvind(), forecast_arvind(), cv_arvind()

Examples

```
dat <- simulate_arvind_data(n = 50, seed = 1)
m5 <- fit_hmm(Y ~ X1 + X2 + X3, dat, nstates = 2, seed = 42)
m5$states
```

---

fit_mixed *Fit Mixed-Effects Regression with Arvind Errors*

Description

Fits a mixed-effects regression model with Arvind-distributed random effects and observation-level errors. Estimation uses a two-stage approach: REML initialisation via **lme4**, followed by Arvind MLE on the residuals.

Usage

```
fit_mixed(formula, data, group_var = "Season", re_formula = NULL, seed = 42)
```

Arguments

formula	an object of class formula specifying the fixed-effects structure.
data	a data frame containing the variables in the formula and the grouping variable.
group_var	character string; the name of the grouping variable in data (default: "Season").
re_formula	optional random-effects formula (e.g., (1 + X1 | group)). If NULL (default), a random intercept model (1 | group_var) is used.
seed	integer; random seed for reproducibility (default: 42).

Value

An object of class "ArvindFit", a list containing the same standard fields as fit_rw1(), plus:

lme_model the fitted lme4::lmer object.

theta_re numeric; Arvind parameter estimated from random effects.

group_var character; the grouping variable name.

See Also

diagnostics_arvind(), forecast_arvind(), cv_arvind()

Examples

```
dat <- simulate_arvind_data(n = 50, seed = 1)
m4 <- fit_mixed(Y ~ X1 + X2 + X3, dat, group_var = "Group", seed = 42)
m4$theta
m4$theta
```

`fit_rw1` *Fit Random Walk on Coefficients Model (RW1-approx)*

Description

Fits a stochastic regression model with time-varying coefficients evolving as a random walk with Arvind-distributed innovations. The observation errors also follow the Arvind distribution.

Usage

```
fit_rw1(formula, data, theta_innov = 2, rw_scale = 0.01, seed = 42)
```

Arguments

`formula`	an object of class `formula` specifying the model (e.g., `Y ~ X1 + X2`).
`data`	a data frame containing the variables in the formula.
`theta_innov`	positive numeric; the Arvind parameter for state innovations (default: 2.0).
`rw_scale`	numeric; proportion of OLS coefficients used as innovation scale (default: 0.01).
`seed`	integer; random seed for reproducibility (default: 42).

Value

An object of class `"ArvindFit"`, a list containing:

model_type character; `"RW1-approx"`.

fitted numeric vector; fitted values.

residuals numeric vector; raw residuals.

theta numeric; estimated Arvind parameter for residuals.

sigma numeric; residual scale.

shift numeric; shift applied to residuals.

e_pos numeric vector; positive standardised residuals.

negloglik numeric; negative log-likelihood.

beta_t matrix; time-varying coefficient paths.

beta_final numeric vector; final coefficient values.

sigma_rw numeric vector; random walk innovation scales.

theta_innov numeric; Arvind parameter used for innovations.

n integer; number of observations.

p integer; number of parameters.

X matrix; design matrix.

Y numeric vector; response variable.

formula the model formula.

data the input data frame.

See Also

diagnostics_arvind(), forecast_arvind(), cv_arvind()

Examples

```
dat <- simulate_arvind_data(n = 50, seed = 1)
m1 <- fit_rw1(Y ~ X1 + X2 + X3, dat, seed = 42)
m1$theta
```

---

fit_simex *Fit Simulation-Extrapolation (SIMEX) Model*

Description

Fits a regression model correcting for measurement error attenuation using the SIMEX algorithm with Arvind-distributed measurement noise and residuals.

Usage

```
fit_simex(
  formula,
  data,
  me_vars = NULL,
  me_frac = 0.05,
  lambda_grid = c(0.5, 1, 1.5, 2),
  n_sim = 100,
  theta_me = 2,
  seed = 123
)
```

Arguments

formula	an object of class formula.
data	a data frame containing the variables in the formula.
me_vars	character vector of covariate names measured with error. If NULL (default), the first two term labels are used.

me_frac	numeric; fraction of marginal variance used as measurement error variance (default: 0.05).
lambda_grid	numeric vector; SIMEX lambda grid (default: c(0.5, 1, 1.5, 2)).
n_sim	integer; number of SIMEX simulation replicates (default: 100).
theta_me	positive numeric; Arvind parameter for measurement error (default: 2.0).
seed	integer; random seed for reproducibility (default: 123).

Value

An object of class "ArvindFit", a list containing the same standard fields as fit_rw1(), plus:

beta numeric vector; SIMEX-corrected coefficient estimates.

simex_coefs matrix; coefficient estimates at each lambda level.

lambda_grid numeric vector; the SIMEX lambda grid used.

me_vars character vector; covariate names with measurement error.

sigma2_me named numeric vector; measurement error variances.

See Also

diagnostics_arvind(), forecast_arvind(), cv_arvind()

Examples

```
dat <- simulate_arvind_data(n = 50, seed = 1)
m3 <- fit_simex(Y ~ X1 + X2 + X3, dat,
                me_vars = c("X1", "X2"),
                n_sim = 20, seed = 123)
m3$beta
m3$beta
```

---

fit_tvlm *Fit Time-Varying Coefficient Linear Model (tvLM)*

Description

Fits a time-varying coefficient linear model using kernel-weighted least squares (via the **tvReg** package) with Arvind-distributed residuals.

Usage

```
fit_tvlm(formula, data, bw = NULL, seed = 42)
```

Arguments

formula	an object of class formula.
data	a data frame containing the variables in the formula.
bw	numeric or NULL; the bandwidth for kernel smoothing. If NULL (default), bandwidth is selected automatically via leave-one-out cross-validation.
seed	integer; random seed for reproducibility (default: 42).

Value

An object of class "ArvindFit", a list containing the same standard fields as fit_rw1(), plus:

tv_coefs matrix; time-varying coefficient estimates.

tv_fit the fitted tvReg::tvLM object.

See Also

diagnostics_arvind(), forecast_arvind(), cv_arvind()

Examples

```
dat <- simulate_arvind_data(n = 50, seed = 1)
m2 <- fit_tvlm(Y ~ X1 + X2 + X3, dat, bw = 0.5, seed = 42)
m2$theta
```

---

forecast_arvind *Monte Carlo Forecasting for Arvind Models*

Description

Generates Monte Carlo forecasts with 80 percent and 95 percent prediction intervals for any fitted ArvindFit model. Covariates are forecast using SARIMA models (via the **forecast** package) if not supplied.

Usage

```
forecast_arvind(
  fit,
  newdata_sims = NULL,
  h = 120,
  nsim = 5000,
  covariate_models = NULL,
  seed = 123
)
```

Arguments

fit	an object of class "ArvindFit".
newdata_sims	optional named list of pre-computed covariate simulation matrices, each of dimension h x nsim.
h	integer; forecast horizon in time steps (default: 120).
nsim	integer; number of Monte Carlo replicates (default: 5000).
covariate_models	optional list of fitted SARIMA models for covariates (auto-fitted if NULL).
seed	integer; random seed for reproducibility (default: 123).

Value

A list with components:

sims matrix (h x nsim); full simulation matrix.

mean numeric vector length h; mean forecast.

median numeric vector length h; median forecast.

lo80 numeric vector; lower 80 percent prediction interval.

hi80 numeric vector; upper 80 percent prediction interval.

lo95 numeric vector; lower 95 percent prediction interval.

hi95 numeric vector; upper 95 percent prediction interval.

See Also

fit_rw1(), diagnostics_arvind(), cv_arvind()

Examples

```
dat <- simulate_arvind_data(n = 50, seed = 1)
m1 <- fit_rw1(Y ~ X1 + X2 + X3, dat, seed = 42)
fc <- forecast_arvind(m1, h = 12, nsim = 100, seed = 42)
head(fc$mean)
```

---

parvind *Arvind Distribution Function (CDF)*

Description

Computes the cumulative distribution function (CDF) of the Arvind distribution.

Usage

```
parvind(q, theta, lower.tail = TRUE)
```

Arguments

q	numeric vector of quantiles.
theta	positive numeric scalar; the distribution parameter.
lower.tail	logical; if TRUE (default), probabilities are $P(X \leq q)$; otherwise $P(X > q)$.

Details

The CDF is given by

$$F(x;\theta) = 1 - \frac{1}{1+\theta x}\exp(-\theta x^2), \quad x > 0.$$

Value

A numeric vector of probabilities.

Examples

```
parvind(1, theta = 1)
parvind(c(0.5, 1, 2), theta = 2)
parvind(1, theta = 1, lower.tail = FALSE)
```

---

plot_arvind *Diagnostic Plots for Arvind Models*

Description

Generates up to 25 diagnostic plots for a fitted ArvindFit object, including observed vs fitted, residual histogram with Arvind density overlay, Q-Q plot, ACF, ECDF comparison, and more.

Usage

```
plot_arvind(fit, output_dir = tempdir(), prefix = NULL)
```

Arguments

fit	an object of class "ArvindFit".
output_dir	character; directory where plots are saved. Defaults to a temporary directory.
prefix	character or NULL; prefix for plot filenames. If NULL, derived from the model type.

Value

The fit object is returned invisibly.

Examples

```
dat <- simulate_arvind_data(n = 50, seed = 1)
m1 <- fit_rw1(Y ~ X1 + X2 + X3, dat, seed = 42)
plot_arvind(m1, output_dir = tempdir())
```

`qarvind` *Arvind Distribution Quantile Function*

Description

Computes quantiles of the Arvind distribution by numerical inversion of the CDF using `uniroot`.

Usage

```
qarvind(p, theta)
```

Arguments

`p`	numeric vector of probabilities ($0 \leq p \leq 1$).
`theta`	positive numeric scalar; the distribution parameter.

Value

A numeric vector of quantiles.

Examples

```
qarvind(0.5, theta = 1)
qarvind(c(0.25, 0.5, 0.75), theta = 2)
```

`rarvind` *Random Generation from the Arvind Distribution*

Description

Generates random variates from the Arvind distribution using a rejection sampling algorithm with a half-normal proposal distribution.

Usage

```
rarvind(n, theta)
```

Arguments

n	positive integer; number of random variates to generate.
theta	positive numeric scalar; the distribution parameter.

Value

A numeric vector of length n containing positive random variates.

Examples

```
set.seed(42)
x <- rarvind(100, theta = 1)
summary(x)
```

---

rarvind_centred *Centred Random Generation from the Arvind Distribution*

Description

Generates centred Arvind variates with approximately zero mean, suitable for use as error terms and innovation terms in stochastic regression models.

Usage

```
rarvind_centred(n, theta)
```

Arguments

n	positive integer; number of random variates to generate.
theta	positive numeric scalar; the distribution parameter.

Details

The centred variate is computed as $\tilde{\varepsilon} = \varepsilon - \mu_A(\theta)$, where $\varepsilon \sim \mathrm{Arvind}(\theta)$ and $\mu_A(\theta)$ is the mean of the Arvind distribution.

Value

A numeric vector of length n with approximately zero mean.

Examples

```
set.seed(42)
eps <- rarvind_centred(1000, theta = 2)
mean(eps)  # approximately 0
```

simulate_arvind_data *Generate Simulated Data for Examples*

Description

Creates a small simulated dataset that mimics the structure needed for demonstrating the **ArvindSt** model-fitting functions. Useful for examples and testing.

Usage

```
simulate_arvind_data(n = 60, seed = 42)
```

Arguments

n	integer; number of observations to generate (default: 60).
seed	integer; random seed for reproducibility (default: 42).

Value

A data frame with columns:

Y numeric; simulated response variable.

X1 numeric; first covariate.

X2 numeric; second covariate.

X3 numeric; third covariate.

Group factor; grouping variable with 4 levels.

Examples

```
dat <- simulate_arvind_data(n = 50, seed = 1)
head(dat)
```

summary_arvind *Summary and Comparison of Multiple Arvind Models*

Description

Accepts multiple `ArvindFit` objects, computes diagnostics for each, produces a unified comparison table, and prints the best model by RMSE, R-squared, and AIC.

Usage

```
summary_arvind(..., comparison_plots = TRUE, output_dir = tempdir())
```

Arguments

`...`	one or more objects of class `"ArvindFit"`.
`comparison_plots`	logical; if `TRUE` (default), generate comparison plots.
`output_dir`	character; directory to save comparison plots. Defaults to a temporary directory.

Value

A data frame of diagnostic metrics (one row per model) is returned invisibly.

See Also

`diagnostics_arvind()`, `plot_arvind()`

Examples

```
dat <- simulate_arvind_data(n = 50, seed = 1)
m1 <- fit_rw1(Y ~ X1 + X2 + X3, dat, seed = 42)
summary_arvind(m1)
```

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