Package ‘mmtdiff’

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Title Moment-Matching Approximation for t-Distribution Differences

Description Implements the moment-matching approximation for differences of non-standardized t-distributed random variables in both univariate and multivariate settings. The package provides density, distribution function, quantile function, and random generation for the approximated distributions of t-differences. The methodology establishes the univariate approximated distributions through the systematic matching of the first, second, and fourth moments, and extends it to multivariate cases, considering both scenarios of independent components and the more general multivariate t-distributions with arbitrary dependence structures. Methods build on the classical moment-matching approximation method (e.g., Casella and Berger (2024) <doi:10.1201/9781003456285>).

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Author Yusuke Yamaguchi [aut, cre]

Maintainer Yusuke Yamaguchi <yamagubed@gmail.com>

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Contents

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mm_tdiff_multivariate_general *Moment-Matching Approximation for General Multivariate t-Differences*

Description

Approximates the distribution of differences between two independent multivariate t-distributed random vectors with arbitrary covariance structure.

Usage

```
mm_tdiff_multivariate_general(mu1, Sigma1, nu1, mu2, Sigma2, nu2)
```

Arguments

`mu1`	Location vector of first distribution (length p)
`Sigma1`	Scale matrix of first distribution (p x p, positive definite)
`nu1`	Degrees of freedom of first distribution (must be > 4)
`mu2`	Location vector of second distribution (length p)
`Sigma2`	Scale matrix of second distribution (p x p, positive definite)
`nu2`	Degrees of freedom of second distribution (must be > 4)

Details

This function handles the general case where components may be correlated within each multivariate t-distribution. The approximation uses a single scalar degrees of freedom parameter to capture the overall tail behavior.

Note: For high dimensions with heterogeneous component behaviors, consider using `mm_tdiff_multivariate_independen` instead.

Value

An S3 object of class "mm_tdiff_multivariate_general" containing:

`mu_diff`	Location vector of difference
`Sigma_star`	Scale matrix
`nu_star`	Degrees of freedom (scalar)
`method`	Character string "multivariate_general"

Examples

```
Sigma1 <- matrix(c(1, 0.3, 0.3, 1), 2, 2)
Sigma2 <- matrix(c(1.5, 0.5, 0.5, 1.2), 2, 2)
result <- mm_tdiff_multivariate_general(
  mu1 = c(0, 1), Sigma1 = Sigma1, nu1 = 10,
  mu2 = c(0, 0), Sigma2 = Sigma2, nu2 = 15
)
print(result)
```

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mm_tdiff_multivariate_independent

Moment-Matching Approximation for Multivariate t-Differences (Independent)

Description

Approximates the distribution of differences between two independent p-dimensional vectors with independent t-distributed components.

Usage

```
mm_tdiff_multivariate_independent(mu1, sigma1, nu1, mu2, sigma2, nu2)
```

Arguments

mu1	Location vector of first distribution (length p)
sigma1	Scale vector of first distribution (length p, all > 0)
nu1	Degrees of freedom vector of first distribution (length p, all > 4)
mu2	Location vector of second distribution (length p)
sigma2	Scale vector of second distribution (length p, all > 0)
nu2	Degrees of freedom vector of second distribution (length p, all > 4)

Details

This function applies the univariate moment-matching approximation component-wise when all components are mutually independent. Each component difference Zj = X1j - X2j is approximated independently using the univariate method.

This approach is optimal for:

- Marginal inference on specific components
- Cases where components have different tail behaviors
- Maintaining computational efficiency in high dimensions

Value

An S3 object of class "mm_tdiff_multivariate_independent" containing:

`mu_diff`	Location vector of difference
`sigma_star`	Vector of scale parameters
`nu_star`	Vector of degrees of freedom
`p`	Dimension of the vectors
`method`	Character string "multivariate_independent"

See Also

`mm_tdiff_multivariate_general` for correlated components

Examples

```
result <- mm_tdiff_multivariate_independent(
  mu1 = c(0, 1), sigma1 = c(1, 1.5), nu1 = c(10, 12),
  mu2 = c(0, 0), sigma2 = c(1.2, 1), nu2 = c(15, 20)
)
print(result)
```

`mm_tdiff_univariate` *Moment-Matching Approximation for Univariate t-Differences*

Description

Approximates the distribution of the difference between two independent non-standardized t-distributed random variables using the moment-matching method.

Usage

```
mm_tdiff_univariate(mu1, sigma1, nu1, mu2, sigma2, nu2)
```

Arguments

`mu1`	Location parameter of first distribution
`sigma1`	Scale parameter of first distribution (must be > 0)
`nu1`	Degrees of freedom of first distribution (must be > 4)
`mu2`	Location parameter of second distribution
`sigma2`	Scale parameter of second distribution (must be > 0)
`nu2`	Degrees of freedom of second distribution (must be > 4)

Details

For two independent non-standardized t-distributed random variables:

- X1 ~ t(mu1, sigma1^2, nu1)
- X2 ~ t(mu2, sigma2^2, nu2)

The difference Z = X1 - X2 is approximated as: Z ~ t(mu1 - mu2, sigma_star^2, nu_star)

where the effective parameters are computed through moment matching:

- sigma_star is derived from the second moment matching
- nu_star is derived from the fourth moment matching

The method requires nu1 > 4 and nu2 > 4 for the existence of fourth moments. The approximation quality improves as degrees of freedom increase and approaches exactness as nu -> infinity (normal limit).

Value

An S3 object of class "mm_tdiff_univariate" containing:

`mu_diff`	Location parameter of difference (mu1 - mu2)
`sigma_star`	Scale parameter
`nu_star`	Degrees of freedom
`input_params`	List of input parameters for reference
`method`	Character string "univariate"

References

Yamaguchi, Y., Homma, G., Maruo, K., & Takeda, K. Moment-Matching Approximation for Difference of Non-Standardized t-Distributed Variables. (unpublished).

See Also

`dtdiff`, `ptdiff`, `qtdiff`, `rtdiff` for density, distribution function, quantile function, and random generation respectively

Examples

```
# Example 1: Different scale parameters
result <- mm_tdiff_univariate(
  mu1 = 0, sigma1 = 1, nu1 = 10,
  mu2 = 0, sigma2 = 1.5, nu2 = 15
)
print(result)

# Example 2: Equal parameters (special case)
result_equal <- mm_tdiff_univariate(
  mu1 = 5, sigma1 = 2, nu1 = 20,
  mu2 = 3, sigma2 = 2, nu2 = 20
```

```
)
print(result_equal)
```

`mvtdiff_distributions` *Distribution Functions for Multivariate Approximated t-Difference*

Description

Distribution Functions for Multivariate Approximated t-Difference

Usage

```
dmvtdiff(x, mm_result, log = FALSE)

pmvtdiff(q, mm_result, lower.tail = TRUE)

rmvtdiff(n, mm_result)
```

Arguments

`x`	Matrix of quantiles (n x p) or vector for single point
`mm_result`	Result from mm_tdiff_multivariate_general()
`log`	Logical; if TRUE, returns log density
`q`	Vector of quantiles (length p) for cumulative probability
`lower.tail`	Logical; if TRUE (default), probabilities are P(X <= x)
`n`	Number of observations

Details

These functions implement the distribution functions for the approximated multivariate t-difference based on Theorem 3 from the paper.

Note on degrees of freedom:

- `dmvtdiff` uses the exact (non-integer) nu_star from the paper
- `pmvtdiff` rounds nu_star to the nearest integer due to mvtnorm::pmvt requirements. This introduces minimal approximation error when nu_star > 10 (the recommended range).
- `rmvtdiff` uses the exact (non-integer) nu_star

Value

For `dmvtdiff`: Numeric vector of density values. For `pmvtdiff`: Numeric scalar of cumulative probability. For `rmvtdiff`: Matrix of random samples (n x p).

Examples

```
# Setup
Sigma1 <- matrix(c(1, 0.3, 0.3, 1), 2, 2)
Sigma2 <- matrix(c(1.5, 0.5, 0.5, 1.2), 2, 2)
result <- mm_tdiff_multivariate_general(
  mu1 = c(0, 1), Sigma1 = Sigma1, nu1 = 10,
  mu2 = c(0, 0), Sigma2 = Sigma2, nu2 = 15
)

# Density at a point
dmvtdiff(c(0, 1), result)

# Density at multiple points
x_mat <- matrix(c(0, 1, -1, 0.5), nrow = 2, byrow = TRUE)
dmvtdiff(x_mat, result)

# Cumulative probability
pmvtdiff(c(0, 1), result)

# Random samples
samples <- rmvtdiff(100, result)
head(samples)
```

`tdiff_distributions` *Distribution Functions for Approximated t-Difference*

Description

Distribution Functions for Approximated t-Difference

Usage

```
dtdiff(x, mm_result)

ptdiff(q, mm_result)

qtdiff(p, mm_result)

rtdiff(n, mm_result)
```

Arguments

`x, q`	Vector of quantiles
`mm_result`	Result from mm_tdiff_univariate()
`p`	Vector of probabilities
`n`	Number of observations

Value

For `dtdiff`: Numeric vector of density values. For `ptdiff`: Numeric vector of cumulative probabilities. For `qtdiff`: Numeric vector of quantiles. For `rtdiff`: Numeric vector of random samples from the approximated t-difference distribution.

Examples

```
result <- mm_tdiff_univariate(0, 1, 10, 0, 1.5, 15)
dtdiff(0, result)
ptdiff(0, result)
qtdiff(c(0.025, 0.975), result)
samples <- rtdiff(100, result)
```

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validate_approximation

Validate Moment-Matching Approximation

Description

Validates the approximation quality by comparing moments of the approximated distribution with the theoretical moments.

Usage

```
validate_approximation(mm_result, n_sim = 10000, seed = NULL)
```

Arguments

`mm_result`	Result from any mm_tdiff function
`n_sim`	Number of simulations for validation (default: 10000)
`seed`	Random seed for reproducibility

Value

A list containing validation metrics

Examples

```
result <- mm_tdiff_univariate(0, 1, 10, 0, 1.5, 15)
validation <- validate_approximation(result)
print(validation)
```

Index