

# Package ‘PosRatioDist’

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**Type** Package

**Title** Quotient of Random Variables Conditioned to the Positive Quadrant

**Version** 1.2.1

**Maintainer** Yuancheng Si <siyuanchengman@gmail.com>

**Description** Computes the exact probability density function of X/Y conditioned on positive quadrant for series of bivariate distributions,for more details see Nadarajah,Song and Si (2019) <[DOI:10.1080/03610926.2019.1576893](https://doi.org/10.1080/03610926.2019.1576893)>.

**Depends** R (>= 3.5.0)

**License** GPL (>= 2)

**Encoding** UTF-8

**Imports** mvtnorm, stats

**NeedsCompilation** no

**RoxygenNote** 7.1.1

**Author** Yuancheng Si [aut, cre] (ORCID:  
<<https://orcid.org/0000-0003-0944-0013>>),  
Saralees Nadarajah [aut],  
Xiaodong Song [ctb]

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dBibs\_expPR

*Bibs\_expPR***Description**

probability density function of quotient of Balakrishna and Shiji's bivariate exponential random variables conditioned to the positive quadrant. For more detailed information please read the first reference paper.

**Usage**

```
dBibs_expPR(x, a, r)
```

**Arguments**

x	vector of positive quantiles.
a	parameter for Balakrishna and Shiji's bivariate exponential distribution
r	parameter for Balakrishna and Shiji's bivariate exponential distribution

**Details**

Probability density function

$$f_R(r | X > 0, Y > 0) = \frac{a}{2\sqrt{r}} \left( r + \frac{a^2}{4r} \right)^{-3/2}$$

For  $r > 0, a > 0$

**Value**

dBibs\_expPR gives the probability density function for quotient of Balakrishna and Shiji's bivariate exponential random variables conditioned to the positive quadrant.

Invalid arguments will return an error message.

**References**

Yuancheng Si and Saralees Nadarajah and Xiaodong Song, (2020). On the distribution of quotient of random variables conditioned to the positive quadrant. *Communications in Statistics - Theory and Methods*, **49**, pp2514-2528.

Balakrishnan, N. and Lai, C. -D. (2009). *Continuous Bivariate Distributions*. Springer Verlag, New York.

Balakrishna, N. and Shiji, K. (2014). On a class of bivariate exponential distributions. *Statistics and Probability Letters*, **85**, pp153-160.

**Examples**

```
x <- seq(0.1,5,0.1)
y <- dBibs_expPR(x, 2, 2)
plot(x,y,type = 'l')
```

---

dBicauchyPR

*BicauchyPR*


---

**Description**

probability density function of quotient of Bivariate cauchy random variables conditioned to the positive quadrant. For more detailed information please read the first reference paper.

**Usage**

```
dBicauchyPR(x, a, b)
```

**Arguments**

x	single real positive scalar
a	parameter for bivariate cauchy distribution
b	parameter for bivariate cauchy distribution

**Details**

Probability density function

$$f_R(r | X > 0, Y > 0) = \frac{1}{2\pi \Pr(X > 0, Y > 0)} J_1 \left( r^2 + 1, Ar + B, C, \frac{3}{2} \right)$$

For  $-\infty < x < \infty, -\infty < y < \infty, r > 0, -\infty < a < \infty, -\infty < b < \infty$ , where  $A = -2a, B = -2b, C = 1 + a^2 + b^2$  and  $J_1$  is given by first reference paper section (2.5).

**Value**

dBicauchyPR gives the probability density function for quotient of Bivariate cauchy random variables conditioned to the positive quadrant.

Invalid arguments will return an error message.

**Author(s)**

Saralees Nadarajah & Yuancheng Si <siyuanchengman@gmail.com>

## References

- Yuancheng Si and Saralees Nadarajah and Xiaodong Song, (2020). On the distribution of quotient of random variables conditioned to the positive quadrant. *Communications in Statistics - Theory and Methods*, **49**, pp2514-2528.
- Balakrishnan, N. and Lai, C. -D. (2009). *Continuous Bivariate Distributions*. Springer Verlag, New York.
- Caginalp, C. and Caginalp, G. (2018). The quotient of normal random variables and application to asset price fat tails. *Physica A—Statistical Mechanics and Its Applications*, **499**, pp457-471.
- Louzada, F., Ara, A. and Fernandes, G. (2017). The bivariate alpha-skew-normal distribution. *Communications in Statistics - Theory and Methods*, **46**, pp7147-7156.
- Nadarajah, S. (2009). A bivariate Pareto model for drought. *Stochastic Environmental Research and Risk Assessment*, **23**, pp811-822.
- Nadarajah, S. and Kotz, S. (2006). Reliability models based on bivariate exponential distributions. *Probabilistic Engineering Mechanics*, **21**, pp338-351.
- Nadarajah, S. and Kotz, S. (2007). Financial Pareto ratios. *Quantitative Finance*, **7**, pp257-260.

## Examples

```
x <- seq(0.1,5,0.1)
y <- c()
for (i in x){y=c(y,dBicauchyPR(i,1,2))}
plot(x,y,type = 'l')
```

---

dBiexpweightedPR

*BiexpweightedPR*

---

## Description

probability density function of quotient of Bivariate exponential random variables resulting from weighted linear combinations conditioned to the positive quadrant. For more detailed information please read the first reference paper.

## Usage

```
dBiexpweightedPR(x, a, b, c)
```

**Arguments**

x	vector of positive quantiles.
a	parameter for Bivariate exponential random variables resulting from weighted linear combinations
b	parameter for Bivariate exponential random variables resulting from weighted linear combinations
c	parameter for Bivariate exponential random variables resulting from weighted linear combinations

**Details**

Probability density function

$$f_R(r | X > 0, Y > 0) = \frac{(1 - 2c) \exp [(1 - 2c)a + b]}{\Pr(X > 0, Y > 0) [1 + (1 - 2c)r]^2}$$

For  $x > a > -\infty, y > b > -\infty, r > 0, 0 < c < 1$ , These correlated exponential random variables can be used to model the stress and strength components of a system, hence the quotient distribution can be used to estimate the probability of failure of the system

**Value**

dBiexpweightedPR gives the probability density function for quotient of Bivariate exponential random variables resulting from weighted linear combinations conditioned to the positive quadrant.

Invalid arguments will return an error message.

**Author(s)**

Saralees Nadarajah & Yuancheng Si <siyuanchengman@gmail.com>

**References**

- Yuancheng Si and Saralees Nadarajah and Xiaodong Song, (2020). On the distribution of quotient of random variables conditioned to the positive quadrant. *Communications in Statistics - Theory and Methods*, **49**, pp2514-2528.
- Balakrishnan, N. and Lai, C. -D. (2009). *Continuous Bivariate Distributions*. Springer Verlag, New York.
- Caginalp, C. and Caginalp, G. (2018). The quotient of normal random variables and application to asset price fat tails. *Physica A—Statistical Mechanics and Its Applications*, **499**, pp457-471.
- Louzada, F., Ara, A. and Fernandes, G. (2017). The bivariate alpha-skew-normal distribution. *Communications in Statistics - Theory and Methods*, **46**, pp7147-7156.
- Nadarajah, S. (2009). A bivariate Pareto model for drought. *Stochastic Environmental Research and Risk Assessment*, **23**, pp811-822.
- Nadarajah, S. and Kotz, S. (2006). Reliability models based on bivariate exponential distributions. *Probabilistic Engineering Mechanics*, **21**, pp338-351.
- Nadarajah, S. and Kotz, S. (2007). Financial Pareto ratios. *Quantitative Finance*, **7**, pp257-260.

**Examples**

```
x <- seq(0.1,5,0.1)
y <- dBexpweightedPR(x, 4, 2, 0.2)
plot(x,y,type = 'l')
```

---

dBilomaxPR

*BilomaxPR*


---

**Description**

probability density function of quotient of Bivariate Lomax random variables conditioned to the positive quadrant. For more detailed information please read the first reference paper.

**Usage**

```
dBilomaxPR(x, a, b, c, alpha, beta, theta)
```

**Arguments**

x	single positive scalar for quotient
a	parameter for Bivariate lomax distribution
b	parameter for Bivariate lomax distribution
c	parameter for Bivariate lomax distribution
alpha	parameter for Bivariate lomax distribution
beta	parameter for Bivariate lomax distribution
theta	parameter for Bivariate lomax distribution

**Details**

Probability density function

$$f_R(r | X > 0, Y > 0) = \frac{c^2 \theta^2 r}{\Pr(X > 0, Y > 0)} J_3(\theta r, \beta - \theta a + (\alpha - \theta b)r, 1 - \alpha a - \beta b + \theta ab, c + 2) + \frac{c^2 \theta [(\alpha - \theta b)r + \beta]}{\Pr(X > 0, Y > 0)}$$

For  $r > 0, \alpha > 0, \beta > 0, \theta > 0, 0 \leq \theta \leq (c + 1)\alpha\beta$  where  $J_1, J_2, J_3$  are given by first reference paper section (2.5)

**Value**

dBilomaxPR gives the probability density function for bivariate lomax random variables conditioned to the positive quadrant.

Invalid arguments will return an error message.

**Author(s)**

Saralees Nadarajah & Yuancheng Si <siyuanchengman@gmail.com>

**References**

Yuancheng Si and Saralees Nadarajah and Xiaodong Song, (2020). On the distribution of quotient of random variables conditioned to the positive quadrant. *Communications in Statistics - Theory and Methods*, **49**, pp2514-2528.

Balakrishnan, N. and Lai, C. -D. (2009). *Continuous Bivariate Distributions*. Springer Verlag, New York.

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dBiMG\_expPR

*BiMG\_expPR*


---

**Description**

probability density function of quotient of Morgenstern type bivariate exponential random variables conditioned to the positive quadrant. For more detailed information please read the first reference paper.

**Usage**

dBiMG\_expPR(x, a, b, alpha)

**Arguments**

x	vector of positive quantiles.
a	parameter for Morgenstern type bivariate exponential distribution
b	parameter for Morgenstern type bivariate exponential distribution
alpha	parameter for Morgenstern type bivariate exponential distribution

**Details**

Probability density function

$$f_R(r | X > 0, Y > 0) = \frac{(1 + \alpha) \exp(a + b)}{\Pr(X > 0, Y > 0)(1 + r)^2} - \frac{2\alpha \exp(a + 2b)}{\Pr(X > 0, Y > 0)(2 + r)^2} - \frac{2\alpha \exp(2a + b)}{\Pr(X > 0, Y > 0)(1 + 2r)^2} + \frac{\alpha^2 \exp(a + b)}{\Pr(X > 0, Y > 0)}$$

For  $r > 0, -1 \leq \alpha \leq 1, a > -\infty, b > -\infty$  These correlated exponential random variables can also be used to model the stress and strength components of a system, hence the quotient distribution can be used to estimate the probability of failure of the system

**Value**

dBiMG\_expPR gives the probability density function for quotient of Morgenstern type bivariate exponential random variables conditioned to the positive quadrant

Invalid arguments will return an error message.

**Author(s)**

Saralees Nadarajah & Yuancheng Si <siyuanchengman@gmail.com>

**References**

Yuancheng Si and Saralees Nadarajah and Xiaodong Song, (2020). On the distribution of quotient of random variables conditioned to the positive quadrant. *Communications in Statistics - Theory and Methods*, **49**, pp2514-2528.

Balakrishnan, N. and Lai, C. -D. (2009). *Continuous Bivariate Distributions*. Springer Verlag, New York.

Balakrishna, N. and Shiji, K. (2014). On a class of bivariate exponential distributions. *Statistics and Probability Letters*, **85**, pp153-160.

**Examples**

```
x <- seq(0.1,5,0.1)
y <- dBIMG_expPR(x, 3, 2, 0.5)
plot(x,y,type = 'l')
```

---

dBinormalPR

*BinormalPR*


---

**Description**

probability density function of quotient of Bivariate normal random variables conditioned to the positive quadrant. For more detailed information please read the first reference paper.

**Usage**

```
dBinormalPR(x, a, b, rho)
```

**Arguments**

x	vector of positive quantiles.
a	parameter
b	parameter
rho	correlation coefficient, $-1 < \rho < 1$

**Details**

Probability density function

$$f_R(r | X > 0, Y > 0) = \frac{1}{2\pi\sqrt{1-\rho^2} \Pr(X > 0, Y > 0)} \exp\left[-\frac{a^2 + b^2 - 2\rho ab}{2(1-\rho^2)}\right] I_1\left(\frac{1 + Cr + r^2}{2(1-\rho^2)}, \frac{Ar + B}{2(1-\rho^2)}\right)$$

For  $-\infty < x < \infty, -\infty < y < \infty, r > 0, -\infty < a < \infty, -\infty < b < \infty, -1 < \rho < 1$ , where  $A = -2a + 2\rho b, B = -2b + 2\rho a, C = -2\rho$



**Value**

dBinormalPR gives the probability density function for quotient of Bivariate normal random variables conditioned to the positive quadrant.

Invalid arguments will return an error message.

**Author(s)**

Saralees Nadarajah & Yuancheng Si <siyuanchengman@gmail.com>

**References**

- Yuancheng Si and Saralees Nadarajah and Xiaodong Song, (2020). On the distribution of quotient of random variables conditioned to the positive quadrant. *Communications in Statistics - Theory and Methods*, **49**, pp2514-2528.
- Balakrishna, N. and Shiji, K. (2014). On a class of bivariate exponential distributions. *Statistics and Probability Letters*, **85**, pp153-160.
- Arnold, B. C. and Strauss, D. (1988). Pseudolikelihood estimation. *Sankhya B*, **53**, pp233-243.
- Caginalp, C. and Caginalp, G. (2018). The quotient of normal random variables and application to asset price fat tails. *Physica A—Statistical Mechanics and Its Applications*, **499**, pp457-471.
- Louzada, F., Ara, A. and Fernandes, G. (2017). The bivariate alpha-skew-normal distribution. *Communications in Statistics - Theory and Methods*, **46**, pp7147-7156.
- Nadarajah, S. (2009). A bivariate Pareto model for drought. *Stochastic Environmental Research and Risk Assessment*, **23**, pp811-822.
- Nadarajah, S. and Kotz, S. (2006). Reliability models based on bivariate exponential distributions. *Probabilistic Engineering Mechanics*, **21**, pp338-351.
- Nadarajah, S. and Kotz, S. (2007). Financial Pareto ratios. *Quantitative Finance*, **7**, pp257-260.

**Examples**

```
x <- seq(0.1,5,0.1)
y <- dBinormalPR(x, 2, 1, 0.5)
plot(x,y,type = 'l')
```

---

 dBiparetoPR

*BiparetoPR*


---

**Description**

probability density function of quotient of Bivariate Pareto random variables conditioned to the positive quadrant. For more detailed information please read the first reference paper.

**Usage**

dBiparetoPR(x)

**Arguments**

`x` vector of positive quantiles.

**Details**

Probability density function

$$f_R(r \mid X > 0, Y > 0) = (r + 1)^{-2}$$

For  $r > 0$ , Nadarajah (2009) used this distribution to model the proportion of droughts defined as a quotient of drought durations and non-drought durations.

**Value**

dBiparetoPR gives the probability density function for quotient of Bivariate Pareto random variables conditioned to the positive quadrant.

Invalid arguments will return an error message.

**Author(s)**

Saralees Nadarajah & Yuancheng Si <siyuanchengman@gmail.com>

**References**

Yuancheng Si and Saralees Nadarajah and Xiaodong Song, (2020). On the distribution of quotient of random variables conditioned to the positive quadrant. *Communications in Statistics - Theory and Methods*, **49**, pp2514-2528.

Mardia, K. V. (1962). Multivariate Pareto distributions. *Annals of Mathematical Statistics*, **33**, 1008-1015.

Nadarajah, S. (2009) A bivariate Pareto model for drought. *Stochastic Environmental Research and Risk Assessment*, **23**, pp811-822.

**Examples**

```
x <- seq(0.1, 5, 0.1)
y <- dBiparetoPR(x)
plot(x, y, type = 'l')
```

---

dBitPR

*BitPR*


---

### Description

probability density function of quotient of Bivariate t random variables conditioned to the positive quadrant. For more detailed information please read the first reference paper.

### Usage

dBitPR(x, a, b, rho, v)

### Arguments

x	single positive scalar, for quotient of Bivariate t random variables conditioned to the positive quadrant
a	parameter for Bivariate t distribution
b	parameter for Bivariate t distribution
rho	correlation coefficient, $-1 < \rho < 1$
v	parameter, degree of freedom of Bivariate t distribution

### Details

Probability density function

$$f_R(r | X > 0, Y > 0) = \frac{\Gamma\left(\frac{\nu+2}{2}\right) \nu^{\frac{\nu}{2}} (1-\rho^2)^{\frac{\nu+1}{2}}}{\Gamma\left(\frac{\nu}{2}\right) \pi \Pr(X > 0, Y > 0)} J_1\left(r^2 - 2\rho r + 1, Ar + B, C + \nu(1-\rho^2), \frac{\nu}{2} + 1\right)$$

For  $-\infty < x < \infty, -\infty < y < \infty, r > 0, -\infty < a < \infty, -\infty < b < \infty, -1 < \rho < 1$ , where  $A = -2a + 2\rho b, B = -2b + 2\rho a, C = a^2 + b^2 - 2\rho ab$  and  $J_1$  is given by first reference paper section (2.5).

### Value

dBitPR gives the probability density function for quotient of Bivariate t random variables conditioned to the positive quadrant.

Invalid arguments will return an error message.

### Author(s)

Saralees Nadarajah & Yuancheng Si <siyuanchengman@gmail.com>

## References

- Yuancheng Si and Saralees Nadarajah and Xiaodong Song, (2020). On the distribution of quotient of random variables conditioned to the positive quadrant. *Communications in Statistics - Theory and Methods*, **49**, pp2514-2528.
- Balakrishnan, N. and Lai, C. -D. (2009). *Continuous Bivariate Distributions*. Springer Verlag, New York.
- Arnold, B. C. and Strauss, D. (1988). Pseudolikelihood estimation. *Sankhya B*, **53**, pp233-243.
- Caginalp, C. and Caginalp, G. (2018). The quotient of normal random variables and application to asset price fat tails. *Physica A—Statistical Mechanics and Its Applications*, **499**, pp457-471.
- Louzada, F., Ara, A. and Fernandes, G. (2017). The bivariate alpha-skew-normal distribution. *Communications in Statistics - Theory and Methods*, **46**, pp7147-7156.
- Nadarajah, S. (2009). A bivariate Pareto model for drought. *Stochastic Environmental Research and Risk Assessment*, **23**, pp811-822.
- Nadarajah, S. and Kotz, S. (2006). Reliability models based on bivariate exponential distributions. *Probabilistic Engineering Mechanics*, **21**, pp338-351.
- Nadarajah, S. and Kotz, S. (2007). Financial Pareto ratios. *Quantitative Finance*, **7**, pp257-260.

## Examples

```
x <- seq(0.1,5,0.1)
y <- c()
for (i in x){y=c(y,dBitPR(i,1,2,0.5,2))}
plot(x,y,type = 'l')
```

---

f21hyper

*f21hyper*

---

## Description

Computes the value of a Gaussian hypergeometric function  $F(a, b, c, z)$  for  $-1 \leq z \leq 1$  and  $a, b, c \geq 0$

## Usage

```
f21hyper(a, b, c, z)
```

## Arguments

- a                    The parameter a of the Gaussian hypergeometric function, must be a positive scalar here
- b                    The parameter b of the Gaussian hypergeometric function, must be a positive scalar here

c	The parameter c of the Gaussian hypergeometric function, must be a positive scalar here
z	The parameter z of the Gaussian hypergeometric function, must be between -1 and 1 here

### Details

The function f21hyper complements the analysis of the 'hyper-g prior' introduced by Liang et al. (2008).

For parameter values, compare cf. [https://en.wikipedia.org/wiki/Hypergeometric\\_function#The\\_series\\_2F1](https://en.wikipedia.org/wiki/Hypergeometric_function#The_series_2F1).

### Value

Invalid arguments will return an error message.

### Author(s)

Martin Feldkircher and Stefan Zeugner

### References

Liang F., Paulo R., Molina G., Clyde M., Berger J.(2008): Mixtures of g-priors for Bayesian variable selection. *J. Am. Statist. Assoc.* 103, p. 410-423

Yuancheng Si and Saralees Nadarajah and Xiaodong Song, (2020). On the distribution of quotient of random variables conditioned to the positive quadrant. *Communications in Statistics - Theory and Methods*, **49**, pp2514-2528.

Saralees Nadarajah and Y.Si (2020) A note on the “L-logistic regression models: Prior sensitivity analysis, robustness to outliers and applications”. *Brazilian Journal of Probability and Statistics*,**34**,p. 183-187.

### Examples

```
f21hyper(30,1,20,.8) #returns about 165.8197
f21hyper(30,10,20,0) #returns one
f21hyper(10,15,20,-0.1) # returns about 0.4872972
```

I\_1

Lemma

**Description**

Technical Lemmas for calculating quotient of random variables conditioned to the positive quadrant. For more detailed information please read the first reference paper section 2.2.

**Usage**

I\_1(a, b)

I\_2(a, b)

I\_3(a, b)

J\_1(a, b, c, alpha)

J\_2(a, b, c, alpha)

J\_3(a, b, c, alpha)

**Arguments**

a parameter

b parameter

c parameter

alpha parameter

**Details** $I_n$  Type I Integration

$$I_n(a, b) = \int_0^{\infty} y^n \exp(-ay^2 - by) dy$$

For  $-\infty < a < \infty$ ,  $-\infty < b < \infty$ , where  $n$  is positive integer.

In particular, for  $a > 0$ , we have expressions below

$$I_1(a, b) = -\frac{\sqrt{\pi}b}{4a^{3/2}} \exp\left(\frac{b^2}{4a}\right) \operatorname{erfc}\left(\frac{b}{2\sqrt{a}}\right) + \frac{1}{2a}$$

$$I_2(a, b) = \frac{\sqrt{\pi}}{4a^{3/2}} \exp\left(\frac{b^2}{4a}\right) \operatorname{erfc}\left(\frac{b}{2\sqrt{a}}\right) + \frac{\sqrt{\pi}b^2}{8a^{5/2}} \exp\left(\frac{b^2}{4a}\right) \operatorname{erfc}\left(\frac{b}{2\sqrt{a}}\right) - \frac{b}{4a^2}$$

$$I_3(a, b) = -\frac{3\sqrt{\pi}b}{8a^{5/2}} \exp\left(\frac{b^2}{4a}\right) \operatorname{erfc}\left(\frac{b}{2\sqrt{a}}\right) - \frac{\sqrt{\pi}b^3}{16a^{7/2}} \exp\left(\frac{b^2}{4a}\right) \operatorname{erfc}\left(\frac{b}{2\sqrt{a}}\right) + \frac{1}{2a^2} + \frac{b^2}{8a^3}$$

$J_n$  Type J Integration

$$J_n(a, b, c, \alpha) = \int_0^{\infty} y^n (ay^2 + by + c)^{-\alpha} dy$$

In particular, for  $a > 0, b^2 < 4ac, -1 < n < 2\alpha - 1$ , we have expressions below

$$J_1(a, b, c, \alpha) = a^{-1} c^{1-\alpha} B(2, 2\alpha - 2) {}_2F_1\left(1, \alpha - 1; \alpha + \frac{1}{2}; 1 - \frac{b^2}{4ac}\right)$$

$$J_2(a, b, c, \alpha) = a^{-\frac{3}{2}} c^{\frac{3}{2}-\alpha} B(3, 2\alpha - 3) {}_2F_1\left(\frac{3}{2}, \alpha - \frac{3}{2}; \alpha + \frac{1}{2}; 1 - \frac{b^2}{4ac}\right)$$

$$J_3(a, b, c, \alpha) = a^{-2} c^{2-\alpha} B(4, 2\alpha - 4) {}_2F_1\left(2, \alpha - 2; \alpha + \frac{1}{2}; 1 - \frac{b^2}{4ac}\right)$$

### Value

I\_1 gives value of Type I integration with  $n = 1$

I\_2 gives value of Type I integration with  $n = 2$

I\_3 gives value of Type I integration with  $n = 3$

J\_1 gives value of Type J integration with  $n = 1$

J\_2 gives value of Type J integration with  $n = 2$

J\_3 gives value of Type J integration with  $n = 3$

Invalid arguments will return an error message.

### Author(s)

Saralees Nadarajah & Yuancheng Si <siyuanchengman@gmail.com>

### References

Yuancheng Si and Saralees Nadarajah and Xiaodong Song, (2020). On the distribution of quotient of random variables conditioned to the positive quadrant. *Communications in Statistics - Theory and Methods*, **49**, pp2514-2528.

Balakrishna, N. and Shiji, K. (2014). On a class of bivariate exponential distributions. *Statistics and Probability Letters*, **85**, pp153-160.

Arnold, B. C. and Strauss, D. (1988). Pseudolikelihood estimation. *Sankhya B*, **53**, pp233-243.

Caginalp, C. and Caginalp, G. (2018). The quotient of normal random variables and application to asset price fat tails. *Physica A—Statistical Mechanics and Its Applications*, **499**, pp457-471.

Louzada, F., Ara, A. and Fernandes, G. (2017). The bivariate alpha-skew-normal distribution. *Communications in Statistics - Theory and Methods*, **46**, pp7147-7156.

Nadarajah, S. (2009). A bivariate Pareto model for drought. *Stochastic Environmental Research and Risk Assessment*, **23**, pp811-822.

Nadarajah, S. and Kotz, S. (2006). Reliability models based on bivariate exponential distributions. *Probabilistic Engineering Mechanics*, **21**, pp338-351.

Nadarajah, S. and Kotz, S. (2007). Financial Pareto ratios. *Quantitative Finance*, **7**, pp257-260.

**Examples** $I_1(1,2)$  $I_2(1,2)$  $I_3(1,2)$  $J_1(1,2,3,3)$  $J_2(1,2,3,3)$  $J_3(1,2,3,3)$



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