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Type Package

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Author Kam Hamidieh <khamidieh@gmail.com>

Maintainer Kam Hamidieh <khamidieh@gmail.com>

Description Extract the implied risk neutral density from options
using various methods.

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License GPL (>= 2)

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RND-package

Risk Neutral Density Extraction Package

Description

This package is a collection of various functions to extract the implied risk neutral density from option.

Details

Package: RND
 Type: Package
 Version: 1.2
 Date: 2017-01-10
 License: GPL (>= 2)

Author(s)

Kam Hamidieh <khamidieh@gmail.com>

References

E. Jondeau and S. Poon and M. Rockinger (2007): *Financial Modeling Under Non-Gaussian Distributions* Springer-Verlag, London

Examples

```
###
### You should see that all methods extract the same density!
###

r      = 0.05
te     = 60/365
s0     = 1000
sigma  = 0.25
y      = 0.02

call.strikes.bsm = seq(from = 500, to = 1500, by = 5)
market.calls.bsm = price.bsm.option(r =r, te = te, s0 = s0,
                                     k = call.strikes.bsm, sigma = sigma, y = y)$call

put.strikes.bsm  = seq(from = 500, to = 1500, by = 5)
market.puts.bsm  = price.bsm.option(r =r, te = te, s0 = s0,
                                     k = put.strikes.bsm, sigma = sigma, y = y)$put

###
### See where your results will be outputted to...
###

getwd()

###
### Running this may take a few minutes...
###
### MOE(market.calls.bsm, call.strikes.bsm, market.puts.bsm,
### put.strikes.bsm, s0, r , te, y, "bsm2")
###
```

approximate.max

Max Function Approximation

Description

approximate.max gives a smooth approximation to the max function.

Usage

```
approximate.max(x, y, k = 5)
```

Arguments

x	the first argument for the max function
y	the second argument for the max function
k	a tuning parameter. The larger this value, the closer the function output to a true max function.

Details

approximate.max approximates the max of x, and y as follows:

$$g(x, y) = \frac{1}{1 + \exp(-k(x - y))}, \quad \max(x, y) \approx xg(x, y) + y(1 - g(x, y))$$

Value

approximate maximum of x and y

Author(s)

Kam Hamidieh

References

Melick, W. R. and Thomas, C.P. (1997) Recovering an asset's implied pdf from option prices: An application to crude oil during the gulf crisis. *Journal of Financial and Quantitative Analysis*, 32(1), 91-115

Examples

```
#
# To see how the max function compares with approximate.max,
# run the following code.
#

i = seq(from = 0, to = 10, by = 0.25)
y = i - 5
max.values = pmax(0,y)
approximate.max.values = approximate.max(0,y,k=5)
matplot(i, cbind(max.values, approximate.max.values), lty = 1, type = "l",
        col=c("black","red"), main = "Max in Black, Approximate Max in Red")
```

bsm.objective	<i>BSM Objective Function</i>
---------------	-------------------------------

Description

bsm.objective is the objective function to be minimized in extract.bsm.density.

Usage

```
bsm.objective(s0, r, te, y, market.calls, call.strikes, call.weights = 1,
             market.puts, put.strikes, put.weights = 1, lambda = 1, theta)
```

Arguments

s0	current asset value
r	risk free rate
te	time to expiration
y	dividend yield
market.calls	market calls (most expensive to cheapest)
call.strikes	strikes for the calls (smallest to largest)
call.weights	weights to be used for calls
market.puts	market calls (cheapest to most expensive)
put.strikes	strikes for the puts (smallest to largest)
put.weights	weights to be used for calls
lambda	Penalty parameter to enforce the martingale condition
theta	initial values for the optimization. This must be a vector of length 2: first component is μ , the lognormal mean of the underlying density, and the second component is $\sqrt{t}\sigma$ which is the time scaled volatility parameter of the underlying density.

Details

This function evaluates the weighted squared differences between the market option values and values predicted by the Black-Scholes-Merton option pricing formula.

Value

Objective function evaluated at a specific set of values.

Author(s)

Kam Hamidieh

References

E. Jondeau and S. Poon and M. Rockinger (2007): *Financial Modeling Under Non-Gaussian Distributions* Springer-Verlag, London

Examples

```

r      = 0.05
te     = 60/365
s0     = 1000
sigma  = 0.25
y      = 0.01

call.strikes = seq(from = 500, to = 1500, by = 25)
market.calls = price.bsm.option(r = r, te = te, s0 = s0,
                                k = call.strikes, sigma = sigma, y = y)$call

put.strikes  = seq(from = 510, to = 1500, by = 25)
market.puts  = price.bsm.option(r = r, te = te, s0 = s0,
                                k = put.strikes, sigma = sigma, y = y)$put

###
### perfect initial values under BSM framework
###

mu.0      = log(s0) + ( r - y - 0.5 * sigma^2 ) * te
zeta.0    = sigma * sqrt(te)
mu.0
zeta.0

###
### The objective function should be *very* small
###

bsm.obj.val = bsm.objective(theta=c(mu.0, zeta.0), r = r, y=y, te = te, s0 = s0,
                              market.calls = market.calls, call.strikes = call.strikes,
                              market.puts  = market.puts,  put.strikes = put.strikes, lambda = 1)
bsm.obj.val

```

compute.implied.volatility

Compute Impied Volatility

Description

compute.implied.volatility extracts the implied volatility for a call option.

Usage

```
compute.implied.volatility(r, te, s0, k, y, call.price, lower, upper)
```



```

bsm.calls
k.range

#
# Computed implied sigma's should be very close to sigma.range.
#

compute.implied.volatility(r = r, te = te, s0 = s0, k = k.range, y = y,
                           call.price = bsm.calls, lower = 0.001, upper = 0.999)
sigma.range

```

dew

Edgeworth Density

Description

dew is the probability density function implied by the Edgeworth expansion method.

Usage

```
dew(x, r, y, te, s0, sigma, skew, kurt)
```

Arguments

x	value at which the density is to be evaluated
r	risk free rate
y	dividend yield
te	time to expiration
s0	current asset value
sigma	volatility
skew	normalized skewness
kurt	normalized kurtosis

Details

This density function attempts to capture deviations from lognormal density by using Edgeworth expansions.

Value

density value at x

Author(s)

Kam Hamidieh

References

- E. Jondeau and S. Poon and M. Rockinger (2007): *Financial Modeling Under Non-Gaussian Distributions* Springer-Verlag, London
- R. Jarrow and A. Rudd (1982) Approximate valuation for arbitrary stochastic processes. *Journal of Financial Economics*, 10, 347-369
- C.J. Corrado and T. Su (1996) S&P 500 index option tests of Jarrow and Rudd's approximate option valuation formula. *Journal of Futures Markets*, 6, 611-629

Examples

```
#
# Look at a true lognorma density & related dew
#
r      = 0.05
y      = 0.03
s0     = 1000
sigma  = 0.25
te     = 100/365
strikes = seq(from=600, to = 1400, by = 1)
v      = sqrt(exp(sigma^2 * te) - 1)
ln.skew = 3 * v + v^3
ln.kurt = 16 * v^2 + 15 * v^4 + 6 * v^6 + v^8

skew.4 = ln.skew * 1.50
kurt.4 = ln.kurt * 1.50

skew.5 = ln.skew * 0.50
kurt.5 = ln.kurt * 2.00

ew.density.4 = dew(x=strikes, r=r, y=y, te=te, s0=s0, sigma=sigma,
                  skew=skew.4, kurt=kurt.4)
ew.density.5 = dew(x=strikes, r=r, y=y, te=te, s0=s0, sigma=sigma,
                  skew=skew.5, kurt=kurt.5)
bsm.density  = dlnorm(x = strikes, meanlog = log(s0) + (r - y - (sigma^2)/2)*te,
                    sdlog = sigma*sqrt(te), log = FALSE)

matplot(strikes, cbind(bsm.density, ew.density.4, ew.density.5), type="l",
        lty=c(1,1,1), col=c("black","red","blue"),
        main="Black = BSM, Red = EW 1.5 Times, Blue = EW 0.50 & 2")
```

Description

dgb is the probability density function of generalized beta distribution.

Usage

```
dgb(x, a, b, v, w)
```

Arguments

x	value at which the density is to be evaluated
a	power parameter > 0
b	scale parameter > 0
v	first beta parameter > 0
w	second beta parameter > 0

Details

Let B be a beta random variable with parameters v and w , then $Z = b(B/(1 - B))^{1/a}$ is a generalized beta with parameters (a, b, v, w) .

Value

density value at x

Author(s)

Kam Hamidieh

References

R.M. Bookstaber and J.B. McDonald (1987) A general distribution for describing security price returns. *Journal of Business*, 60, 401-424

X. Liu and M.B. Shackleton and S.J. Taylor and X. Xu (2007) Closed-form transformations from risk-neutral to real-world distributions *Journal of Business*, 60, 401-424

E. Jondeau and S. Poon and M. Rockinger (2007): *Financial Modeling Under Non-Gaussian Distributions* Springer-Verlag, London

Examples

```
#
# Just simple plot of the density
#

x = seq(from = 500, to = 1500, length.out = 10000)
a = 10
b = 1000
v = 3
w = 3
dx = dgb(x = x, a = a, b = b, v = v, w = w)
plot(dx ~ x, type="l")
```

dmln	<i>Density of Mixture Lognormal</i>
------	-------------------------------------

Description

dmln is the probability density function of a mixture of two lognormal densities.

Usage

```
dmln(x, alpha.1, meanlog.1, meanlog.2, sdlog.1, sdlog.2)
```

Arguments

x	value at which the density is to be evaluated
alpha.1	proportion of the first lognormal. Second one is 1 - alpha.1
meanlog.1	mean of the log of the first lognormal
meanlog.2	mean of the log of the second lognormal
sdlog.1	standard deviation of the log of the first lognormal
sdlog.2	standard deviation of the log of the second lognormal

Details

dmln is the density $f(x) = \alpha.1 * g(x) + (1 - \alpha.1) * h(x)$, where g and h are densities of two lognormals with parameters (mean.log.1, sdlog.1) and (mean.log.2, sdlog.2) respectively.

Value

out	density value at x
-----	--------------------

Author(s)

Kam Hamidieh

References

- B. Bahra (1996): Probability distribution of future asset prices implied by option prices. *Bank of England Quarterly Bulletin*, August 1996, 299-311
- P. Soderlind and L.E.O. Svensson (1997) New techniques to extract market expectations from financial instruments. *Journal of Monetary Economics*, 40, 383-429
- E. Jondeau and S. Poon and M. Rockinger (2007): *Financial Modeling Under Non-Gaussian Distributions* Springer-Verlag, London

Examples

```

#
# A bimodal risk neutral density!
#

m1n.alpha.1 = 0.4
m1n.meanlog.1 = 6.3
m1n.meanlog.2 = 6.5
m1n.sdlog.1 = 0.08
m1n.sdlog.2 = 0.06

k = 300:900
dx = dmln(x = k, alpha.1 = m1n.alpha.1, meanlog.1 = m1n.meanlog.1,
          meanlog.2 = m1n.meanlog.2,
          sdlog.1 = m1n.sdlog.1, sdlog.2 = m1n.sdlog.2)
plot(dx ~ k, type="l")

```

dmln.am

Density of Mixture Lognormal for American Options

Description

dmln.am is the probability density function of a mixture of three lognormal densities.

Usage

```
dmln.am(x, u.1, u.2, u.3, sigma.1, sigma.2, sigma.3, p.1, p.2)
```

Arguments

x	value at which the density is to be evaluated
u.1	log mean of the first lognormal
u.2	log mean of the second lognormal
u.3	log mean of the third lognormal
sigma.1	log standard deviation of the first lognormal
sigma.2	log standard deviation of the second lognormal
sigma.3	log standard deviation of the third lognormal
p.1	weight assigned to the first density
p.2	weight assigned to the second density

Details

dmln is density $f(x) = p.1 * f1(x) + p.2 * f2(x) + (1 - p.1 - p.2) * f3(x)$, where f1, f2, and f3 are lognormal densities with log means u.1, u.2, and u.3 and standard deviations sigma.1, sigma.2, and sigma.3 respectively.

Value

out density value at x

Author(s)

Kam Hamidieh

References

Melick, W. R. and Thomas, C. P. (1997). Recovering an asset's implied pdf from option prices: An application to crude oil during the gulf crisis. *Journal of Financial and Quantitative Analysis*, 32(1), 91-115.

Examples

```
###
### Just look at a generic density and see if it integrates to 1.
###

u.1   = 4.2
u.2   = 4.5
u.3   = 4.8
sigma.1 = 0.30
sigma.2 = 0.20
sigma.3 = 0.15
p.1   = 0.25
p.2   = 0.45
x = seq(from = 0, to = 250, by = 0.01)
y = dmln.am(x = x, u.1 = u.1, u.2 = u.2, u.3 = u.3, sigma.1 = sigma.1, sigma.2 = sigma.2,
           sigma.3 = sigma.3, p.1 = p.1, p.2 = p.2)

plot(y ~ x, type="l")
sum(y * 0.01)

###
### Yes, the sum is near 1.
###
```

dshimko

Density Implied by Shimko Method

Description

dshimko is the probability density function implied by the Shimko method.

Usage

```
dshimko(r, te, s0, k, y, a0, a1, a2)
```

Arguments

r	risk free rate
te	time to expiration
s0	current asset value
k	strike at which volatility to be computed
y	dividend yield
a0	constant term in the quadratic polynomial
a1	coefficient term of k in the quadratic polynomial
a2	coefficient term of k squared in the quadratic polynomial

Details

The implied volatility is modeled as: $\sigma(k) = a_0 + a_1k + a_2k^2$

Value

density value at x

Author(s)

Kam Hamidieh

References

D. Shimko (1993) Bounds of probability. *Risk*, 6, 33-47

E. Jondeau and S. Poon and M. Rockinger (2007): *Financial Modeling Under Non-Gaussian Distributions* Springer-Verlag, London

Examples

```
#
# a0, a1, a2 values come from Shimko's paper.
#

r      = 0.05
y      = 0.02
a0     = 0.892
a1     = -0.00387
a2     = 0.00000445
te     = 60/365
s0     = 400
k      = seq(from = 250, to = 500, by = 1)
sigma = 0.15

#
# Does it look like a proper density and intergate to one?
#
```

```

dx = dshimko(r = r, te = te, s0 = s0, k = k, y = y, a0 = a0, a1 = a1, a2 = a2)
plot(dx ~ k, type="l")

#
# sum(dx) should be about 1 since dx is a density.
#

sum(dx)

```

ew.objective

Edgeworth Exapnsion Objective Function

Description

ew.objective is the objective function to be minimized in ew.extraction.

Usage

```
ew.objective(theta, r, y, te, s0, market.calls, call.strikes, call.weights = 1,
             lambda = 1)
```

Arguments

theta	initial values for the optimization
r	risk free rate
y	dividend yield
te	time to expiration
s0	current asset value
market.calls	market calls (most expensive to cheapest)
call.strikes	strikes for the calls (smallest to largest)
call.weights	weights to be used for calls
lambda	Penalty parameter to enforce the martingale condition

Details

This function evaluates the weighted squared differences between the market option values and values predicted by Edgeworth based expansion of the risk neutral density.

Value

Objective function evaluated at a specific set of values

Author(s)

Kam Hamidieh

References

- E. Jondeau and S. Poon and M. Rockinger (2007): *Financial Modeling Under Non-Gaussian Distributions* Springer-Verlag, London
- R. Jarrow and A. Rudd (1982) Approximate valuation for arbitrary stochastic processes. *Journal of Financial Economics*, 10, 347-369
- C.J. Corrado and T. Su (1996) S&P 500 index option tests of Jarrow and Rudd's approximate option valuation formula. *Journal of Futures Markets*, 6, 611-629

Examples

```

r      = 0.05
y      = 0.03
s0     = 1000
sigma  = 0.25
te     = 100/365
k      = seq(from=800, to = 1200, by = 50)
v      = sqrt(exp(sigma^2 * te) - 1)
ln.skew = 3 * v + v^3
ln.kurt = 16 * v^2 + 15 * v^4 + 6 * v^6 + v^8

#
# The objective function should be close to zero.
# Also the weights are automatically set to 1.
#

market.calls.bsm = price.bsm.option(r = r, te = te, s0 = s0, k=k,
                                   sigma=sigma, y=y)$call
ew.objective(theta = c(sigma, ln.skew, ln.kurt), r = r, y = y, te = te, s0=s0,
              market.calls = market.calls.bsm, call.strikes = k, lambda = 1)

```

extract.am.density *Mixture of Lognormal Extraction for American Options*

Description

extract.am.density extracts the mixture of three lognormals from American options.

Usage

```

extract.am.density(initial.values = rep(NA, 10), r, te, s0, market.calls,
                  call.weights = NA, market.puts, put.weights = NA, strikes, lambda = 1,
                  hessian.flag = F, cl = list(maxit = 10000))

```


Arguments

initial.values	initial values for the optimization
r	risk free rate
te	time to expiration
s0	current asset value
market.calls	market calls (most expensive to cheapest)
call.weights	weights to be used for calls. Set to 1 by default.
market.puts	market calls (cheapest to most expensive)
put.weights	weights to be used for puts. Set to 1 by default.
strikes	strikes (smallest to largest)
lambda	Penalty parameter to enforce the martingale condition
hessian.flag	If FALSE then no Hessian is produced
c1	List of parameter values to be passed to the optimization function

Details

The extracted density is in the form of $f(x) = p.1 * f1(x) + p.2 * f2(x) + (1 - p.1 - p.2) * f3(x)$, where $f1$, $f2$, and $f3$ are lognormal densities with log means $u.1, u.2$, and $u.3$ and standard deviations $\sigma.1, \sigma.2$, and $\sigma.3$ respectively.

For the description of $w.1$ and $w.2$ see equations (7) & (8) of Melick and Thomas paper below.

Value

w.1	First weight, a number between 0 and 1, to weigh the option price bounds
w.2	Second weight, a number between 0 and 1, to weigh the option price bounds
u.1	log mean of the first lognormal
u.2	log mean of the second lognormal
u.3	log mean of the third lognormal
sigma.1	log sd of the first lognormal
sigma.2	log sd of the second lognormal
sigma.3	log sd of the third lognormal
p.1	weight assigned to the first density
p.2	weight assigned to the second density
converge.result	Captures the convergence result
hessian	Hessian Matrix

Author(s)

Kam Hamidieh

References

Melick, W. R. and Thomas, C. P. (1997). Recovering an asset's implied pdf from option prices: An application to crude oil during the gulf crisis. *Journal of Financial and Quantitative Analysis*, 32(1), 91-115.

Examples

```
###
### Try with synthetic data first.
###

r      = 0.01
te     = 60/365
w.1    = 0.4
w.2    = 0.25
u.1    = 4.2
u.2    = 4.5
u.3    = 4.8
sigma.1 = 0.30
sigma.2 = 0.20
sigma.3 = 0.15
p.1    = 0.25
p.2    = 0.45
theta  = c(w.1,w.2,u.1,u.2,u.3,sigma.1,sigma.2,sigma.3,p.1,p.2)
p.3    = 1 - p.1 - p.2

###
### Generate some synthetic American calls & puts
###

expected.f0 = sum(c(p.1, p.2, p.3) * exp(c(u.1,u.2,u.3) +
      (c(sigma.1, sigma.2, sigma.3)^2)/2) )
expected.f0

strikes = 50:150

market.calls = numeric(length(strikes))
market.puts  = numeric(length(strikes))

for (i in 1:length(strikes))
{
  if ( strikes[i] < expected.f0) {
    market.calls[i] = price.am.option(k = strikes[i], r = r, te = te, w = w.1, u.1 = u.1,
      u.2 = u.2, u.3 = u.3, sigma.1 = sigma.1, sigma.2 = sigma.2,
      sigma.3 = sigma.3, p.1 = p.1, p.2 = p.2)$call.value

    market.puts[i] = price.am.option(k = strikes[i], r = r, te = te, w = w.2, u.1 = u.1,
      u.2 = u.2, u.3 = u.3, sigma.1 = sigma.1, sigma.2 = sigma.2,
      sigma.3 = sigma.3, p.1 = p.1, p.2 = p.2)$put.value
  } else {
```

```

market.calls[i] = price.am.option(k = strikes[i], r = r, te = te, w = w.2, u.1 = u.1,
                                u.2 = u.2, u.3 = u.3, sigma.1 = sigma.1, sigma.2 = sigma.2,
                                sigma.3 = sigma.3, p.1 = p.1, p.2 = p.2)$call.value

market.puts[i] = price.am.option(k = strikes[i], r = r, te = te, w = w.1, u.1 = u.1,
                                u.2 = u.2, u.3 = u.3, sigma.1 = sigma.1, sigma.2 = sigma.2,
                                sigma.3 = sigma.3, p.1 = p.1, p.2 = p.2)$put.value
}

}

###
### ** IMPORTANT **: The code that follows may take 1-2 minutes.
###                      Copy and paste onto R console the commands
###                      that follow the greater sign >.
###
### Try the optimization with exact initial values.
### They should be close the actual initials.
###
#
# > s0      = expected.f0 * exp(-r * te)
# > s0
#
# > extract.am.density(initial.values = theta, r = r, te = te, s0 = s0,
#                      market.calls = market.calls, market.puts = market.puts, strikes = strikes,
#                      lambda = 1, hessian.flag = FALSE)
#
# > theta
#
###
### Now try without our the correct initial values...
###
#
# > optim.obj.no.init = extract.am.density( r = r, te = te, s0 = s0,
#                      market.calls = market.calls, market.puts = market.puts, strikes = strikes,
#                      lambda = 1, hessian.flag = FALSE)
#
# > optim.obj.no.init
# > theta
#
###
### We do get different values but how do the densities look like?
###
#
###
### plot the two densities side by side
###
#
# > x = 10:190
#
# > y.1 = dmln.am(x = x, p.1 = theta[9], p.2 = theta[10],
#                u.1 = theta[3], u.2 = theta[4], u.3 = theta[5],

```

```

#           sigma.1 = theta[6], sigma.2 = theta[7], sigma.3 = theta[8] )
#
# > o = optim.obj.no.init
#
# > y.2 = dmln.am(x = x, p.1 = o$p.1, p.2 = o$p.2,
#           u.1 = o$u.1, u.2 = o$u.2, u.3 = o$u.3,
#           sigma.1 = o$sigma.1, sigma.2 = o$sigma.2, sigma.3 = o$sigma.3 )
#
# > matplot(x, cbind(y.1,y.2), main = "Exact = Black, Approx = Red", type="l", lty=1)
#
###
### Densities are close.
###

```

extract.bsm.density *Extract Lognormal Density*

Description

bsm.extraction extracts the parameters of the lognormal density as implied by the BSM model.

Usage

```

extract.bsm.density(initial.values = c(NA, NA), r, y, te, s0, market.calls,
  call.strikes, call.weights = 1, market.puts, put.strikes, put.weights = 1,
  lambda = 1, hessian.flag = F, cl = list(maxit = 10000))

```

Arguments

initial.values	initial values for the optimization
r	risk free rate
y	dividend yield
te	time to expiration
s0	current asset value
market.calls	market calls (most expensive to cheapest)
call.strikes	strikes for the calls (smallest to largest)
call.weights	weights to be used for calls
market.puts	market calls (cheapest to most expensive)
put.strikes	strikes for the puts (smallest to largest)
put.weights	weights to be used for puts
lambda	Penalty parameter to enforce the martingale condition
hessian.flag	if F, no hessian is produced
cl	list of parameter values to be passed to the optimization function

Details

If `initial.values` are not specified then the function will attempt to pick them automatically. `cl` is a list that can be used to pass parameters to the `optim` function.

Value

Let `S_T` with the lognormal random variable of the risk neutral density.

<code>mu</code>	mean of $\log(S_T)$
<code>zeta</code>	sd of $\log(S_T)$
<code>converge.result</code>	Did the result converge?
<code>hessian</code>	Hessian matrix

Author(s)

Kam Hamidieh

References

E. Jondeau and S. Poon and M. Rockinger (2007): *Financial Modeling Under Non-Gaussian Distributions* Springer-Verlag, London

J. Hull (2011) *Options, Futures, and Other Derivatives and DerivaGem Package* Prentice Hall, Englewood Cliffs, New Jersey, 8th Edition

R. L. McDonald (2013) *Derivatives Markets* Pearson, Upper Saddle River, New Jersey, 3rd Edition

Examples

```
#
# Create some BSM Based options
#

r      = 0.05
te     = 60/365
s0     = 1000
sigma  = 0.25
y      = 0.01

call.strikes = seq(from = 500, to = 1500, by = 25)
market.calls = price.bsm.option(r = r, te = te, s0 = s0,
                               k = call.strikes, sigma = sigma, y = y)$call

put.strikes  = seq(from = 510, to = 1500, by = 25)
market.puts  = price.bsm.option(r = r, te = te, s0 = s0,
                               k = put.strikes, sigma = sigma, y = y)$put

#
# Get extract the parameter of the density
#
```

```

extract.bsm.density(r = r, y = y, te = te, s0 = s0, market.calls = market.calls,
                  call.strikes = call.strikes, market.puts = market.puts,
                  put.strikes = put.strikes, lambda = 1, hessian.flag = FALSE)

#
# The extracted parameters should be close to these actual values:
#
actual.mu      = log(s0) + ( r - y - 0.5 * sigma^2) * te
actual.zeta    = sigma * sqrt(te)
actual.mu
actual.zeta

```

extract.ew.density *Extract Edgeworth Based Density*

Description

ew.extraction extracts the parameters for the density approximated by the Edgeworth expansion method.

Usage

```

extract.ew.density(initial.values = c(NA, NA, NA), r, y, te, s0, market.calls,
                  call.strikes, call.weights = 1, lambda = 1, hessian.flag = F,
                  cl = list(maxit = 10000))

```

Arguments

initial.values	initial values for the optimization
r	risk free rate
y	dividend yield
te	time to expiration
s0	current asset value
market.calls	market calls (most expensive to cheapest)
call.strikes	strikes for the calls (smallest to largest)
call.weights	weights to be used for calls
lambda	Penalty parameter to enforce the martingale condition
hessian.flag	if F, no hessian is produced
cl	list of parameter values to be passed to the optimization function

Details

If initial.values are not specified then the function will attempt to pick them automatically. cl in form of a list can be used to pass parameters to the opt im function.

Value

sigma	volatility of the underlying lognormal
skew	normalized skewness
kurt	normalized kurtosis
converge.result	Did the result converge?
hessian	Hessian matrix

Author(s)

Kam Hamidieh

References

- E. Jondeau and S. Poon and M. Rockinger (2007): *Financial Modeling Under Non-Gaussian Distributions* Springer-Verlag, London
- R. Jarrow and A. Rudd (1982) Approximate valuation for arbitrary stochastic processes. *Journal of Financial Economics*, 10, 347-369
- C.J. Corrado and T. Su (1996) S&P 500 index option tests of Jarrow and Rudd's approximate option valuation formula. *Journal of Futures Markets*, 6, 611-629

Examples

```
#
# ln.skew & ln.kurt are the normalized skewness and kurtosis of a true lognormal.
#

r      = 0.05
y      = 0.03
s0     = 1000
sigma  = 0.25
te     = 100/365
strikes = seq(from=600, to = 1400, by = 1)
v      = sqrt(exp(sigma^2 * te) - 1)
ln.skew = 3 * v + v^3
ln.kurt = 16 * v^2 + 15 * v^4 + 6 * v^6 + v^8

#
# Now "perturb" the lognormal
#

new.skew = ln.skew * 1.50
new.kurt = ln.kurt * 1.50

#
# new.skew & new.kurt should not be extracted.
# Note that weights are automatically set to 1.
#
```

```

market.calls      = price.ew.option(r = r, te = te, s0 = s0, k=strikes, sigma=sigma,
                                y=y, skew = new.skew, kurt = new.kurt)$call
ew.extracted.obj  = extract.ew.density(r = r, y = y, te = te, s0 = s0,
                                market.calls = market.calls, call.strikes = strikes,
                                lambda = 1, hessian.flag = FALSE)
ew.extracted.obj

```

extract.gb.density *Generalized Beta Extraction*

Description

extract.gb.density extracts the generalized beta density from market options.

Usage

```

extract.gb.density(initial.values = c(NA, NA, NA, NA), r, te, y, s0, market.calls,
                  call.strikes, call.weights = 1, market.puts, put.strikes, put.weights = 1,
                  lambda = 1, hessian.flag = F, cl = list(maxit = 10000))

```

Arguments

initial.values	initial values for the optimization
r	risk free rate
te	time to expiration
y	dividend yield
s0	current asset value
market.calls	market calls (most expensive to cheapest)
call.strikes	strikes for the calls (smallest to largest)
call.weights	weights to be used for calls
market.puts	market calls (cheapest to most expensive)
put.strikes	strikes for the puts (smallest to largest)
put.weights	weights to be used for puts
lambda	Penalty parameter to enforce the martingale condition
hessian.flag	if F, no hessian is produced
cl	list of parameter values to be passed to the optimization function

Details

This function extracts the generalized beta density implied by the options.

Value

a	extracted power parameter
b	extracted scale paramter
v	extracted first beta paramter
w	extracted second beta parameter
converge.result	Did the result converge?
hessian	Hessian matrix

Author(s)

Kam Hamidieh

References

R.M. Bookstaber and J.B. McDonald (1987) A general distribution for describing security price returns. *Journal of Business*, 60, 401-424

X. Liu and M.B. Shackleton and S.J. Taylor and X. Xu (2007) Closed-form transformations from risk-neutral to real-world distributions *Journal of Business*, 60, 401-424

E. Jondeau and S. Poon and M. Rockinger (2007): *Financial Modeling Under Non-Gaussian Distributions* Springer-Verlag, London

Examples

```
#
# create some GB based calls and puts
#

r = 0.03
te = 50/365
k = seq(from = 800, to = 1200, by = 10)
a = 10
b = 1000
v = 2.85
w = 2.85
y = 0.01
s0 = exp((y-r)*te) * b * beta(v + 1/a, w - 1/a)/beta(v,w)
s0

call.strikes = seq(from = 800, to = 1200, by = 10)
market.calls = price.gb.option(r = r, te = te, y = y, s0 = s0,
                              k = call.strikes, a = a, b = s0, v = v, w = w)$call

put.strikes = seq(from = 805, to = 1200, by = 10)
market.puts = price.gb.option(r = r, te = te, y = y, s0 = s0,
                              k = put.strikes, a = a, b = s0, v = v, w = w)$put

#
```

```
# Extraction...should match the a,b,v,w above. You will also get warning messages.
# Weights are automatically set to 1.
#
extract.gb.density(r=r, te=te, y = y, s0=s0, market.calls = market.calls,
                  call.strikes = call.strikes, market.puts = market.puts,
                  put.strikes = put.strikes, lambda = 1, hessian.flag = FALSE)
```

extract.mln.density *Extract Mixture of Lognormal Densities*

Description

mln.extraction extracts the parameters of the mixture of two lognormals densities.

Usage

```
extract.mln.density(initial.values = c(NA, NA, NA, NA, NA), r, y, te, s0,
                   market.calls, call.strikes, call.weights = 1, market.puts, put.strikes,
                   put.weights = 1, lambda = 1, hessian.flag = F, cl = list(maxit = 10000))
```

Arguments

initial.values	initial values for the optimization
r	risk free rate
y	dividend yield
te	time to expiration
s0	current asset value
market.calls	market calls (most expensive to cheapest)
call.strikes	strikes for the calls (smallest to largest)
call.weights	weights to be used for calls
market.puts	market calls (cheapest to most expensive)
put.strikes	strikes for the puts (smallest to largest)
put.weights	weights to be used for puts
lambda	Penalty parameter to enforce the martingale condition
hessian.flag	if F, no hessian is produced
cl	list of parameter values to be passed to the optimization function

Details

mln is the density $f(x) = \alpha.1 * g(x) + (1 - \alpha.1) * h(x)$, where g and h are densities of two lognormals with parameters (mean.log.1, sdlog.1) and (mean.log.2, sdlog.2) respectively.

Value

alpha.1	extracted proportion of the first lognormal. Second one is 1 - alpha.1
meanlog.1	extracted mean of the log of the first lognormal
meanlog.2	extracted mean of the log of the second lognormal
sdlog.1	extracted standard deviation of the log of the first lognormal
sdlog.2	extracted standard deviation of the log of the second lognormal
converge.result	Did the result converge?
hessian	Hessian matrix

Author(s)

Kam Hamidieh

References

- F. Gianluca and A. Roncoroni (2008) *Implementing Models in Quantitative Finance: Methods and Cases*
- B. Bahra (1996): Probability distribution of future asset prices implied by option prices. *Bank of England Quarterly Bulletin*, August 1996, 299-311
- P. Soderlind and L.E.O. Svensson (1997) New techniques to extract market expectations from financial instruments. *Journal of Monetary Economics*, 40, 383-4
- E. Jondeau and S. Poon and M. Rockinger (2007): *Financial Modeling Under Non-Gaussian Distributions* Springer-Verlag, London

Examples

```
#
# Create some calls and puts based on mln and
# see if we can extract the correct values.
#

r      = 0.05
y      = 0.02
te     = 60/365
meanlog.1 = 6.8
meanlog.2 = 6.95
sdlog.1  = 0.065
sdlog.2  = 0.055
alpha.1  = 0.4

call.strikes = seq(from = 800, to = 1200, by = 10)
market.calls = price.mln.option(r = r, y = y, te = te, k = call.strikes,
                               alpha.1 = alpha.1, meanlog.1 = meanlog.1, meanlog.2 = meanlog.2,
                               sdlog.1 = sdlog.1, sdlog.2 = sdlog.2)$call
```

```

s0 = price.mln.option(r = r, y = y, te = te, k = call.strikes, alpha.1 = alpha.1,
                    meanlog.1 = meanlog.1, meanlog.2 = meanlog.2,
                    sdlog.1 = sdlog.1, sdlog.2 = sdlog.2)$s0

s0
put.strikes = seq(from = 805, to = 1200, by = 10)
market.puts = price.mln.option(r = r, y = y, te = te, k = put.strikes,
                              alpha.1 = alpha.1, meanlog.1 = meanlog.1,
                              meanlog.2 = meanlog.2, sdlog.1 = sdlog.1,
                              sdlog.2 = sdlog.2)$put

###
### The extracted values should be close to the actual values.
###

extract.mln.density(r = r, y = y, te = te, s0 = s0, market.calls = market.calls,
                  call.strikes = call.strikes, market.puts = market.puts,
                  put.strikes = put.strikes, lambda = 1, hessian.flag = FALSE)

```

extract.rates

Extract Risk Free Rate and Dividend Yield

Description

extract.rates extracts the risk free rate and the dividend yield from European options.

Usage

```
extract.rates(calls, puts, s0, k, te)
```

Arguments

calls	market calls (most expensive to cheapest)
puts	market puts (cheapest to most expensive)
s0	current asset value
k	strikes for the calls (smallest to largest)
te	time to expiration

Details

The extraction is based on the put-call parity of the European options. Shimko (1993) - see below - shows that the slope and intercept of the regression of the calls minus puts onto the strikes contains the risk free and the dividend rates.

Value

risk.free.rate	extracted risk free rate
dividend.yield	extracted dividend rate

Author(s)

Kam Hamidieh

ReferencesD. Shimko (1993) Bounds of probability. *Risk*, 6, 33-47**Examples**

```

#
# Create calls and puts based on BSM
#

r      = 0.05
te     = 60/365
s0     = 1000
k      = seq(from = 900, to = 1100, by = 25)
sigma  = 0.25
y      = 0.01

bsm.obj = price.bsm.option(r = r, te = te, s0 = s0, k = k, sigma = sigma, y = y)

calls = bsm.obj$call
puts  = bsm.obj$put

#
# Extract rates should give the values of r and y above:
#

rates = extract.rates(calls = calls, puts = puts, k = k, s0 = s0, te = te)
rates

```

extract.shimko.density

Extract Risk Neutral Density based on Shimko's Method

Description

shimko.extraction extracts the implied risk neutral density based on modeling the volatility as a quadratic function of the strikes.

Usage

```
extract.shimko.density(market.calls, call.strikes, r, y, te, s0, lower, upper)
```

Arguments

market.calls	market calls (most expensive to cheapest)
call.strikes	strikes for the calls (smallest to largest)
r	risk free rate
y	dividend yield
te	time to expiration
s0	current asset value
lower	lower bound for the search of implied volatility
upper	upper bound for the search of implied volatility

Details

The correct values for range of search must be specified.

Value

implied.curve.obj	variable that holds a0, a1, and a2 which are the constant terms of the quadratic polynomial
shimko.density	density evaluated at the strikes
implied.volatilities	implied volatilities at each call.strike

Author(s)

Kam Hamidieh

References

D. Shimko (1993) Bounds of probability. *Risk*, 6, 33-47

E. Jondeau and S. Poon and M. Rockinger (2007): *Financial Modeling Under Non-Gaussian Distributions* Springer-Verlag, London

Examples

```
#
# Test the function shimko.extraction. If BSM holds then a1 = a2 = 0.
#

r      = 0.05
y      = 0.02
te     = 60/365
s0     = 1000
k      = seq(from = 800, to = 1200, by = 5)
sigma  = 0.25

bsm.calls = price.bsm.option(r = r, te = te, s0 = s0, k = k,
```

```

                                sigma = sigma, y = y)$call
extract.shimko.density(market.calls = bsm.calls, call.strikes = k, r = r, y = y, te = te,
                        s0 = s0, lower = -10, upper = 10)

#
# Note: a0 is about equal to sigma, and a1 and a2 are close to zero.
#

```

```
fit.implied.volatility.curve
```

Fit Implied Quadratic Volatility Curve

Description

fit.implied.volatility.curve estimates the coefficients of the quadratic equation for the implied volatilities.

Usage

```
fit.implied.volatility.curve(x, k)
```

Arguments

x	a set of implied volatilities
k	range of strikes

Details

This function estimates volatility σ as a quadratic function of strike k with the coefficients a_0, a_1, a_2 :

$$\sigma(k) = a_0 + a_1k + a_2k^2$$

Value

a0	constant term in the quadratic polynomial
a1	coefficient term of k in the quadratic polynomial
a2	coefficient term of k squared in the quadratic polynomial
summary.obj	statistical summary of the fit

Author(s)

Kam Hamidieh

References

D. Shimko (1993) Bounds of probability. *Risk*, 6, 33-47
 E. Jondeau and S. Poon and M. Rockinger (2007): *Financial Modeling Under Non-Gaussian Distributions* Springer-Verlag, London

Examples

```
#
# Suppose we see the following implied volatilities and strikes:
#

implied.sigma = c(0.11, 0.08, 0.065, 0.06, 0.05)
strikes       = c(340, 360, 380, 400, 410)
tmp          = fit.implied.volatility.curve(x = implied.sigma, k = strikes)
tmp

strike.range = 340:410
plot(implied.sigma ~ strikes)
lines(strike.range, tmp$a0 + tmp$a1 * strike.range + tmp$a2 * strike.range^2)
```

gb.objective

Generalized Beta Objective

Description

gb.objective is the objective function to be minimized in extract.gb.density.

Usage

```
gb.objective(theta, r, te, y, s0, market.calls, call.strikes, call.weights = 1,
             market.puts, put.strikes, put.weights = 1, lambda = 1)
```

Arguments

theta	initial values for optimization
r	risk free rate
te	time to expiration
y	dividend yield
s0	current asset value
market.calls	market calls (most expensive to cheapest)
call.strikes	strikes for the calls (smallest to largest)
call.weights	weights to be used for calls
market.puts	market calls (cheapest to most expensive)
put.strikes	strikes for the puts (smallest to largest)
put.weights	weights to be used for puts
lambda	Penalty parameter to enforce the martingale condition

Details

This is the function minimized by extract.gb.density function.

Value

obj value of the objective function

Author(s)

Kam Hamidieh

References

R.M. Bookstaber and J.B. McDonald (1987) A general distribution for describing security price returns. *Journal of Business*, 60, 401-424

X. Liu and M.B. Shackleton and S.J. Taylor and X. Xu (2007) Closed-form transformations from risk-neutral to real-world distributions *Journal of Business*, 60, 401-424

E. Jondeau and S. Poon and M. Rockinger (2007): *Financial Modeling Under Non-Gaussian Distributions* Springer-Verlag, London

Examples

```
#
# The objective should be very small!
# Note the weights are automatically
# set to 1.
#

r = 0.03
te = 50/365
k = seq(from = 800, to = 1200, by = 10)
a = 10
b = 1000
v = 2.85
w = 2.85
y = 0.01
s0 = exp((y-r)*te) * b * beta(v + 1/a, w - 1/a)/beta(v,w)
s0

call.strikes = seq(from = 800, to = 1200, by = 10)
market.calls = price.gb.option(r = r, te = te, s0 = s0, y = y,
                              k = call.strikes, a = a, b = b, v = v, w = w)$call

put.strikes = seq(from = 805, to = 1200, by = 10)
market.puts = price.gb.option(r = r, te = te, s0 = s0, y = y,
                              k = put.strikes, a = a, b = b, v = v, w = w)$put

gb.objective(theta=c(a,b,v,w),r = r, te = te, y = y, s0 = s0,
             market.calls = market.calls, call.strikes = call.strikes,
             market.puts = market.puts, put.strikes = put.strikes, lambda = 1)
```

get.point.estimate *Point Estimation of the Density*

Description

get.point.estimate estimates the risk neutral density by center differentiation.

Usage

```
get.point.estimate(market.calls, call.strikes, r, te)
```

Arguments

market.calls	market calls (most expensive to cheapest)
call.strikes	strikes for the calls (smallest to largest)
r	risk free rate
te	time to expiration

Details

This is a non-parametric estimate of the risk neutral density. Due to center differentiation, the density values are not estimated at the highest and lowest strikes.

Value

point.estimates
values of the estimated density at each strike

Author(s)

Kam Hamidieh

References

J. Hull (2011) *Options, Futures, and Other Derivatives and DerivaGem Package* Prentice Hall, Englewood Cliffs, New Jersey, 8th Edition

Examples

```
###  
### Recover the lognormal density based on BSM  
###  
  
r      = 0.05  
te     = 60/365  
s0     = 1000  
k      = seq(from = 500, to = 1500, by = 1)  
sigma  = 0.25
```

```

y      = 0.01

bsm.calls = price.bsm.option(r =r, te = te, s0 = s0, k = k, sigma = sigma, y = y)$call
density.est = get.point.estimate(market.calls = bsm.calls,
                                call.strikes = k, r = r , te = te)

len = length(k)-1
### Note, estimates at two data points (smallest and largest strikes) are lost
plot(density.est ~ k[2:len], type = "l")

```

mIn.am.objective	<i>Objective function for the Mixture of Lognormal of American Options</i>
------------------	--

Description

mIn.am.objective is the objective function to be minimized in extract.am.density.

Usage

```

mIn.am.objective(theta, s0, r, te, market.calls, call.weights = NA, market.puts,
                 put.weights = NA, strikes, lambda = 1)

```

Arguments

theta	initial values for the optimization
s0	current asset value
r	risk free rate
te	time to expiration
market.calls	market calls (most expensive to cheapest)
call.weights	weights to be used for calls
market.puts	market calls (cheapest to most expensive)
put.weights	weights to be used for calls
strikes	strikes for the calls (smallest to largest)
lambda	Penalty parameter to enforce the martingale condition

Details

mIn is density $f(x) = p.1 * f1(x) + p.2 * f2(x) + (1 - p.1 - p.2) * f3(x)$, where $f1$, $f2$, and $f3$ are lognormal densities with log means $u.1, u.2$, and $u.3$ and standard deviations $\sigma.1$, $\sigma.2$, and $\sigma.3$ respectively.

Value

obj	Value of the objective function
-----	---------------------------------

Author(s)

Kam Hamidieh

References

Melick, W. R. and Thomas, C. P. (1997). Recovering an asset's implied pdf from option prices: An application to crude oil during the gulf crisis. *Journal of Financial and Quantitative Analysis*, 32(1), 91-115.

Examples

```

r      = 0.01
te     = 60/365
w.1   = 0.4
w.2   = 0.25
u.1   = 4.2
u.2   = 4.5
u.3   = 4.8
sigma.1 = 0.30
sigma.2 = 0.20
sigma.3 = 0.15
p.1   = 0.25
p.2   = 0.45
theta = c(w.1,w.2,u.1,u.2,u.3,sigma.1,sigma.2,sigma.3,p.1,p.2)

p.3 = 1 - p.1 - p.2
p.3
expected.f0 = sum(c(p.1, p.2, p.3) * exp(c(u.1,u.2,u.3) +
      (c(sigma.1, sigma.2, sigma.3)^2)/2) )
expected.f0

strikes = 30:170

market.calls = numeric(length(strikes))
market.puts  = numeric(length(strikes))

for (i in 1:length(strikes))
{
  if ( strikes[i] < expected.f0) {
    market.calls[i] = price.am.option(k = strikes[i], r = r, te = te, w = w.1, u.1 = u.1,
      u.2 = u.2, u.3 = u.3, sigma.1 = sigma.1, sigma.2 = sigma.2,
      sigma.3 = sigma.3, p.1 = p.1, p.2 = p.2)$call.value

    market.puts[i] = price.am.option(k = strikes[i], r = r, te = te, w = w.2, u.1 = u.1,
      u.2 = u.2, u.3 = u.3, sigma.1 = sigma.1, sigma.2 = sigma.2,
      sigma.3 = sigma.3, p.1 = p.1, p.2 = p.2)$put.value
  } else {

    market.calls[i] = price.am.option(k = strikes[i], r = r, te = te, w = w.2, u.1 = u.1,
      u.2 = u.2, u.3 = u.3, sigma.1 = sigma.1, sigma.2 = sigma.2,
      sigma.3 = sigma.3, p.1 = p.1, p.2 = p.2)$call.value
  }
}

```

```

market.puts[i] = price.am.option(k = strikes[i], r = r, te = te, w = w.1, u.1 = u.1,
                                u.2 = u.2, u.3 = u.3, sigma.1 = sigma.1, sigma.2 = sigma.2,
                                sigma.3 = sigma.3, p.1 = p.1, p.2 = p.2)$put.value
}

}

###
### Quickly look at the option values...
###

par(mfrow=c(1,2))
plot(market.calls ~ strikes, type="l")
plot(market.puts ~ strikes, type="l")
par(mfrow=c(1,1))

###
### ** IMPORTANT **: The code that follows may take a few seconds.
###                      Copy and paste onto R console the commands
###                      that follow the greater sign >.
###
###
### Next try the objective function. It should be zero.
### Note: Let weights be the defaults values of 1.
###
#
# > s0      = expected.f0 * exp(-r * te)
# > s0
#
# > mIn.am.objective(theta, s0 =s0, r = r, te = te, market.calls = market.calls,
#                      market.puts = market.puts, strikes = strikes, lambda = 1)
#
###
### Now directly try the optimization with perfect initial values.
###
#
#
# > optim.obj.with.synthetic.data = optim(theta, mIn.am.objective, s0 = s0, r=r, te=te,
#                      market.calls = market.calls, market.puts = market.puts, strikes = strikes,
#                      lambda = 1, hessian = FALSE , control=list(maxit=10000) )
#
# > optim.obj.with.synthetic.data
#
# > theta
#
###
### It does take a few seconds but the optim converges to exact theta values.
###

```

Description

mIn.objective is the objective function to be minimized in extract.mIn.density.

Usage

```
mIn.objective(theta, r, y, te, s0, market.calls, call.strikes, call.weights,
              market.puts, put.strikes, put.weights, lambda = 1)
```

Arguments

theta	initial values for the optimization
r	risk free rate
y	dividend yield
te	time to expiration
s0	current asset value
market.calls	market calls (most expensive to cheapest)
call.strikes	strikes for the calls (smallest to largest)
call.weights	weights to be used for calls
market.puts	market calls (cheapest to most expensive)
put.strikes	strikes for the puts (smallest to largest)
put.weights	weights to be used for puts
lambda	Penalty parameter to enforce the martingale condition

Details

mIn is the density $f(x) = \alpha.1 * g(x) + (1 - \alpha.1) * h(x)$, where g and h are densities of two lognormals with parameters (mean.log.1, sdlog.1) and (mean.log.2, sdlog.2) respectively.

Value

obj	value of the objective function
-----	---------------------------------

Author(s)

Kam Hamidieh

References

- F. Gianluca and A. Roncoroni (2008) *Implementing Models in Quantitative Finance: Methods and Cases*
- B. Bahra (1996): Probability distribution of future asset prices implied by option prices. *Bank of England Quarterly Bulletin*, August 1996, 299-311
- P. Soderlind and L.E.O. Svensson (1997) New techniques to extract market expectations from financial instruments. *Journal of Monetary Economics*, 40, 383-429
- E. Jondeau and S. Poon and M. Rockinger (2007): *Financial Modeling Under Non-Gaussian Distributions* Springer-Verlag, London

Examples

```

#
# The mln objective function should be close to zero.
# The weights are automatically set to 1.
#

r = 0.05
te = 60/365
y = 0.02

meanlog.1 = 6.8
meanlog.2 = 6.95
sdlog.1 = 0.065
sdlog.2 = 0.055
alpha.1 = 0.4

# This is the current price implied by parameter values:
s0 = 981.8815

call.strikes = seq(from = 800, to = 1200, by = 10)
market.calls = price.mln.option(r=r, y = y, te = te, k = call.strikes,
                               alpha.1 = alpha.1, meanlog.1 = meanlog.1, meanlog.2 = meanlog.2,
                               sdlog.1 = sdlog.1, sdlog.2 = sdlog.2)$call

put.strikes = seq(from = 805, to = 1200, by = 10)
market.puts = price.mln.option(r = r, y = y, te = te, k = put.strikes,
                               alpha.1 = alpha.1, meanlog.1 = meanlog.1, meanlog.2 = meanlog.2,
                               sdlog.1 = sdlog.1, sdlog.2 = sdlog.2)$put

mln.objective(theta=c(alpha.1,meanlog.1, meanlog.2 , sdlog.1, sdlog.2),
              r = r, y = y, te = te, s0 = s0,
              market.calls = market.calls, call.strikes = call.strikes,
              market.puts = market.puts, put.strikes = put.strikes, lambda = 1)

```

MOE

Mother of All Extractions

Description

MOE function extracts the risk neutral density based on all models and summarizes the results.

Usage

```
MOE(market.calls, call.strikes, market.puts, put.strikes, call.weights = 1,
    put.weights = 1, lambda = 1, s0, r, te, y, file.name = "myfile")
```

Arguments

market.calls market calls (most expensive to cheapest)

<code>call.strikes</code>	strikes for the calls (smallest to largest)
<code>market.puts</code>	market calls (cheapest to most expensive)
<code>put.strikes</code>	strikes for the puts (smallest to largest)
<code>call.weights</code>	Weights for the calls (must be in the same order of calls)
<code>put.weights</code>	Weights for the puts (must be in the same order of puts)
<code>lambda</code>	Penalty parameter to enforce the martingale condition
<code>s0</code>	Current asset value
<code>r</code>	risk free rate
<code>te</code>	time to expiration
<code>y</code>	dividend yield
<code>file.name</code>	File names where analysis is to be saved. SEE DETAILS!

Details

The MOE function in a few key strokes extracts the risk neutral density via various methods and summarizes the results.

This function should only be used for European options.

NOTE: Three files will be produced: `filename` will have the pdf version of the results. `filename.calls.csv` will have the predicted call values. `filename.puts.csv` will have the predicted put values.

Value

<code>bsm.mu</code>	mean of $\log(S(T))$, when $S(T)$ is lognormal
<code>bsm.sigma</code>	SD of $\log(S(T))$, when $S(T)$ is lognormal
<code>gb.a</code>	extracted power parameter, when $S(T)$ is assumed to be a GB rv
<code>gb.b</code>	extracted scale parameter, when $S(T)$ is assumed to be a GB rv
<code>gb.v</code>	extracted first beta parameter, when $S(T)$ is assumed to be a GB rv
<code>gb.w</code>	extracted second beta parameter, when $S(T)$ is assumed to be a GB rv
<code>mln.alpha.1</code>	extracted proportion of the first lognormal. Second one is $1 - \text{alpha.1}$ in mixture of lognormals
<code>mln.meanlog.1</code>	extracted mean of the log of the first lognormal in mixture of lognormals
<code>mln.meanlog.2</code>	extracted mean of the log of the second lognormal in mixture of lognormals
<code>mln.sdlog.1</code>	extracted standard deviation of the log of the first lognormal in mixture of lognormals
<code>mln.sdlog.2</code>	extracted standard deviation of the log of the second lognormal in mixture of lognormals
<code>ew.sigma</code>	volatility when using the Edgeworth expansions
<code>ew.skew</code>	normalized skewness when using the Edgeworth expansions
<code>ew.kurt</code>	normalized kurtosis when using the Edgeworth expansions
<code>a0</code>	extracted constant term in the quadratic polynomial of Shimko method
<code>a1</code>	extracted coefficient term of k in the quadratic polynomial of Shimko method
<code>a2</code>	extracted coefficient term of k squared in the quadratic polynomial of Shimko method

Author(s)

Kam Hamidieh

References

E. Jondeau and S. Poon and M. Rockinger (2007): *Financial Modeling Under Non-Gaussian Distributions* Springer-Verlag, London

Examples

```
###
### You should see that all methods extract the same density!
###

r      = 0.05
te     = 60/365
s0     = 1000
sigma  = 0.25
y      = 0.02

strikes = seq(from = 500, to = 1500, by = 5)
bsm.prices = price.bsm.option(r = r, te = te, s0 = s0,
                             k = strikes, sigma = sigma, y = y)

calls   = bsm.prices$call
puts    = bsm.prices$put

###
### See where your results will go...
###

getwd()

###
### Running this may take 1-2 minutes...
###
### MOE(market.calls = calls, call.strikes = strikes, market.puts = puts,
###     put.strikes = strikes, call.weights = 1, put.weights = 1,
###     lambda = 1, s0 = s0, r = r, te = te, y = y, file.name = "myfile")
###
### You may get some warning messages. This happens because the
### automatic initial value selection sometimes picks values
### that produce NaNs in the generalized beta density estimation.
### These messages are often inconsequential.
###
```

`oil.2012.10.01`*West Texas Intermediate Crude Oil Options on 2013-10-01*

Description

This dataset contains West Texas Intermediate (WTI) crude oil options with 43 days to expiration at the end of the business day October 1, 2012. On October 1, 2012, WTI closed at 92.44.

Usage

```
data(oil.2012.10.01)
```

Format

A data frame with 332 observations on the following 7 variables.

`type` a factor with levels C for call option P for put option

`strike` option strike

`settlement` option settlement price

`openint` option open interest

`volume` trading volume

`delta` option delta

`impliedvolatility` option implied volatility

Source

CME posts sample data at: <http://www.cmegroup.com/market-data/datamine-historical-data/endofday.html>

Examples

```
data(oil.2012.10.01)
```

`pgb`*CDF of Generalized Beta*

Description

`pgb` is the cumulative distribution function (CDF) of a generalized beta random variable.

Usage

```
pgb(x, a, b, v, w)
```

Arguments

x	value at which the CDF is to be evaluated
a	power parameter > 0
b	scale paramter > 0
v	first beta paramter > 0
w	second beta parameter > 0

Details

Let B be a beta random variable with parameters v and w. Then $Z = b * (B/(1-B))^{1/a}$ is a generalized beta random variable with parameters (a,b,v,w).

Value

out CDF value at x

Author(s)

Kam Hamidieh

References

R.M. Bookstaber and J.B. McDonald (1987) A general distribution for describing security price returns. *Journal of Business*, 60, 401-424

X. Liu and M.B. Shackleton and S.J. Taylor and X. Xu (2007) Closed-form transformations from risk-neutral to real-world distributions *Journal of Business*, 60, 401-424

E. Jondeau and S. Poon and M. Rockinger (2007): *Financial Modeling Under Non-Gaussian Distributions* Springer-Verlag, London

Examples

```
#
# What does the cdf of a GB look like?
#

a = 1
b = 10
v = 2
w = 2

x = seq(from = 0, to = 500, by = 0.01)
y = pgb(x = x, a = a, b = b, v = v, w = w)
plot(y ~ x, type = "l")
abline(h=c(0,1), lty=2)
```

price.am.option	<i>Price American Options on Mixtures of Lognormals</i>
-----------------	---

Description

price.am.option gives the price of a call and a put option at a set strike when the risk neutral density is a mixture of three lognormals.

Usage

price.am.option(k, r, te, w, u.1, u.2, u.3, sigma.1, sigma.2, sigma.3, p.1, p.2)

Arguments

k	Strike
r	risk free rate
te	time to expiration
w	Weight, a number between 0 and 1, to weigh the option price bounds
u.1	log mean of the first lognormal
u.2	log mean of the second lognormal
u.3	log mean of the second lognormal
sigma.1	log sd of the first lognormal
sigma.2	log mean of the second lognormal
sigma.3	log mean of the third lognormal
p.1	weight assigned to the first density
p.2	weight assigned to the second density

Details

mln is density $f(x) = p.1 * f1(x) + p.2 * f2(x) + (1 - p.1 - p.2) * f3(x)$, where $f1$, $f2$, and $f3$ are lognormal densities with log means $u.1, u.2$, and $u.3$ and standard deviations $sigma.1$, $sigma.2$, and $sigma.3$ respectively.

Note: Different weight values, w , need to be assigned to whether the call or put is in the money or not. See equations (7) & (8) of Melick and Thomas paper below.

Value

call.value	American call value
put.value	American put value
expected.f0	Expected mean value of asset at expiration
prob.f0.gr.k	Probability asset values is greater than strike
prob.f0.ls.k	Probability asset value is less than strike

```

expected.f0.f0.gr.k
    Expected value of asset given asset exceeds strike
expected.f0.f0.ls.k
    Expected value of asset given asset is less than strike

```

Author(s)

Kam Hamidieh

References

Melick, W. R. and Thomas, C. P. (1997). Recovering an asset's implied pdf from option prices: An application to crude oil during the gulf crisis. *Journal of Financial and Quantitative Analysis*, 32(1), 91-115.

Examples

```

###
### Set a few parameters and create some
### American options.
###

r      = 0.01
te     = 60/365
w.1    = 0.4
w.2    = 0.25
u.1    = 4.2
u.2    = 4.5
u.3    = 4.8
sigma.1 = 0.30
sigma.2 = 0.20
sigma.3 = 0.15
p.1    = 0.25
p.2    = 0.45
theta  = c(w.1,w.2,u.1,u.2,u.3,sigma.1,sigma.2,sigma.3,p.1,p.2)

p.3 = 1 - p.1 - p.2
p.3
expected.f0 = sum(c(p.1, p.2, p.3) * exp(c(u.1,u.2,u.3) +
    (c(sigma.1, sigma.2, sigma.3)^2)/2) )
expected.f0

strikes = 30:170

market.calls = numeric(length(strikes))
market.puts  = numeric(length(strikes))

for (i in 1:length(strikes))
{
  if ( strikes[i] < expected.f0) {
    market.calls[i] = price.am.option(k = strikes[i], r = r, te = te, w = w.1, u.1 = u.1,

```

```

        u.2 = u.2, u.3 = u.3, sigma.1 = sigma.1, sigma.2 = sigma.2,
        sigma.3 = sigma.3, p.1 = p.1, p.2 = p.2)$call.value

    market.puts[i] = price.am.option(k = strikes[i], r = r, te = te, w = w.2, u.1 = u.1,
        u.2 = u.2, u.3 = u.3, sigma.1 = sigma.1, sigma.2 = sigma.2,
        sigma.3 = sigma.3, p.1 = p.1, p.2 = p.2)$put.value
} else {

    market.calls[i] = price.am.option(k = strikes[i], r = r, te = te, w = w.2, u.1 = u.1,
        u.2 = u.2, u.3 = u.3, sigma.1 = sigma.1, sigma.2 = sigma.2,
        sigma.3 = sigma.3, p.1 = p.1, p.2 = p.2)$call.value

    market.puts[i] = price.am.option(k = strikes[i], r = r, te = te, w = w.1, u.1 = u.1,
        u.2 = u.2, u.3 = u.3, sigma.1 = sigma.1, sigma.2 = sigma.2,
        sigma.3 = sigma.3, p.1 = p.1, p.2 = p.2)$put.value
}
}

###
### Quickly look at the option values...
###

par(mfrow=c(1,2))
plot(market.calls ~ strikes, type="l")
plot(market.puts ~ strikes, type="l")
par(mfrow=c(1,1))

```

price.bsm.option *Price BSM Option*

Description

bsm.option.price computes the BSM European option prices.

Usage

```
price.bsm.option(s0, k, r, te, sigma, y)
```

Arguments

s0	current asset value
k	strike
r	risk free rate
te	time to expiration
sigma	volatility
y	dividend yield

Details

This function implements the classic Black-Scholes-Merton option pricing model.

Value

d1	value of $(\log(s_0/k) + (r - y + (\sigma^2)/2) * te) / (\sigma * \sqrt{te})$
d2	value of $d1 - \sigma * \sqrt{te}$
call	call price
put	put price

Author(s)

Kam Hamidieh

References

E. Jondeau and S. Poon and M. Rockinger (2007): *Financial Modeling Under Non-Gaussian Distributions* Springer-Verlag, London

J. Hull (2011) *Options, Futures, and Other Derivatives and DerivaGem Package* Prentice Hall, Englewood Cliffs, New Jersey, 8th Edition

R. L. McDonald (2013) *Derivatives Markets* Pearson, Upper Saddle River, New Jersey, 3rd Edition

Examples

```
#
# call should be 4.76, put should be 0.81, from Hull 8th, page 315, 316
#

r      = 0.10
te     = 0.50
s0     = 42
k      = 40
sigma  = 0.20
y      = 0

bsm.option = price.bsm.option(r = r, te = te, s0 = s0, k = k, sigma = sigma, y = y)
bsm.option

#
# Make sure put-call parity holds, Hull 8th, page 351
#

(bsm.option$call - bsm.option$put) - (s0 * exp(-y*te) - k * exp(-r*te))
```

price.ew.option *Price Options with Edgeworth Approximated Density*

Description

price.ew.option computes the option prices based on Edgeworth approximated densities.

Usage

```
price.ew.option(r, te, s0, k, sigma, y, skew, kurt)
```

Arguments

r	risk free rate
te	time to expiration
s0	current asset value
k	strike
sigma	volatility
y	dividend rate
skew	normalized skewness
kurt	normalized kurtosis

Details

Note that this function may produce negative prices if skew and kurt are not well estimated from the data.

Value

call	Edgeworth based call
put	Edgeworth based put

Author(s)

Kam Hamidieh

References

- E. Jondeau and S. Poon and M. Rockinger (2007): *Financial Modeling Under Non-Gaussian Distributions* Springer-Verlag, London
- R. Jarrow and A. Rudd (1982) Approximate valuation for arbitrary stochastic processes. *Journal of Financial Economics*, 10, 347-369
- C.J. Corrado and T. Su (1996) S&P 500 index option tests of Jarrow and Rudd's approximate option valuation formula. *Journal of Futures Markets*, 6, 611-629

Examples

```

#
# Here, the prices must match EXACTLY the BSM prices:
#

r      = 0.05
y      = 0.03
s0     = 1000
sigma  = 0.25
te     = 100/365
k      = seq(from=800, to = 1200, by = 50)
v      = sqrt(exp(sigma^2 * te) - 1)
ln.skew = 3 * v + v^3
ln.kurt = 16 * v^2 + 15 * v^4 + 6 * v^6 + v^8

ew.option.prices = price.ew.option(r = r, te = te, s0 = s0, k=k, sigma=sigma,
                                y=y, skew = ln.skew, kurt = ln.kurt)
bsm.option.prices = price.bsm.option(r = r, te = te, s0 = s0, k=k, sigma=sigma, y=y)

ew.option.prices
bsm.option.prices

###
### Now ew prices should be different as we increase the skewness and kurtosis:
###

new.skew = ln.skew * 1.10
new.kurt = ln.kurt * 1.10

new.ew.option.prices = price.ew.option(r = r, te = te, s0 = s0, k=k, sigma=sigma,
                                y=y, skew = new.skew, kurt = new.kurt)

new.ew.option.prices
bsm.option.prices

```

price.gb.option	<i>Generalized Beta Option Pricing</i>
-----------------	--

Description

price.gb.option computes the price of options.

Usage

```
price.gb.option(r, te, s0, k, y, a, b, v, w)
```

Arguments

r risk free interest rate

te	time to expiration
s0	current asset value
k	strike
y	dividend yield
a	power parameter > 0
b	scale paramter > 0
v	first beta paramter > 0
w	second beta parameter > 0

Details

This function is used to compute European option prices when the underlying has a generalized beta (GB) distribution. Let B be a beta random variable with parameters v and w . Then $Z = b * (B/(1-B))^{1/a}$ is a generalized beta random variable with parameters with (a,b,v,w) .

Value

prob.1	Probability that a GB random variable with parameters $(a,b,v+1/a,w-1/a)$ will be above the strike
prob.2	Probability that a GB random variable with parameters (a,b,v,w) will be above the strike
call	call price
put	put price

Author(s)

Kam Hamidieh

References

R.M. Bookstaber and J.B. McDonald (1987) A general distribution for describing security price returns. *Journal of Business*, 60, 401-424

X. Liu and M.B. Shackleton and S.J. Taylor and X. Xu (2007) Closed-form transformations from risk-neutral to real-world distributions *Journal of Business*, 60, 401-424

E. Jondeau and S. Poon and M. Rockinger (2007): *Financial Modeling Under Non-Gaussian Distributions* Springer-Verlag, London

Examples

```
#
# A basic GB option pricing....
#

r = 0.03
te = 50/365
s0 = 1000.086
```

```

k = seq(from = 800, to = 1200, by = 10)
y = 0.01
a = 10
b = 1000
v = 2.85
w = 2.85

```

```
price.gb.option(r = r, te = te, s0 = s0, k = k, y = y, a = a, b = b, v = v, w = w)
```

price.mln.option *Price Options on Mixture of Lognormals*

Description

mln.option.price gives the price of a call and a put option at a strike when the risk neutral density is a mixture of two lognormals.

Usage

```
price.mln.option(r, te, y, k, alpha.1, meanlog.1, meanlog.2, sdlog.1, sdlog.2)
```

Arguments

r	risk free rate
te	time to expiration
y	dividend yield
k	strike
alpha.1	proportion of the first lognormal. Second one is 1 - alpha.1
meanlog.1	mean of the log of the first lognormal
meanlog.2	mean of the log of the second lognormal
sdlog.1	standard deviation of the log of the first lognormal
sdlog.2	standard deviation of the log of the second lognormal

Details

mln is the density $f(x) = \alpha.1 * g(x) + (1 - \alpha.1) * h(x)$, where g and h are densities of two lognormals with parameters (mean.log.1, sdlog.1) and (mean.log.2, sdlog.2) respectively.

Value

call	call price
put	put price
s0	current value of the asset as implied by the mixture distribution

Author(s)

Kam Hamidieh

References

F. Gianluca and A. Roncoroni (2008) *Implementing Models in Quantitative Finance: Methods and Cases*

B. Bahra (1996): Probability distribution of future asset prices implied by option prices. *Bank of England Quarterly Bulletin*, August 1996, 299-311

P. Soderlind and L.E.O. Svensson (1997) New techniques to extract market expectations from financial instruments. *Journal of Monetary Economics*, 40, 383-429

E. Jondeau and S. Poon and M. Rockinger (2007): *Financial Modeling Under Non-Gaussian Distributions* Springer-Verlag, London

Examples

```
#
# Try out a range of options
#

r = 0.05
te = 60/365
k = 700:1300
y = 0.02
meanlog.1 = 6.80
meanlog.2 = 6.95
sdlog.1 = 0.065
sdlog.2 = 0.055
alpha.1 = 0.4

mIn.prices = price.mIn.option(r = r, y = y, te = te, k = k, alpha.1 = alpha.1,
  meanlog.1 = meanlog.1, meanlog.2 = meanlog.2, sdlog.1 = sdlog.1, sdlog.2 = sdlog.2)

par(mfrow=c(1,2))
plot(mIn.prices$call ~ k)
plot(mIn.prices$put ~ k)
par(mfrow=c(1,1))
```

price.shimko.option *Price Option based on Shimko's Method*

Description

price.shimko.option prices a European option based on the extracted Shimko volatility function.

Usage

```
price.shimko.option(r, te, s0, k, y, a0, a1, a2)
```

Arguments

r	risk free rate
te	time to expiration
s0	current asset value
k	strike
y	dividend yield
a0	constant term in the quadratic polynomial
a1	coefficient term of k in the quadratic polynomial
a2	coefficient term of k squared in the quadratic polynomial

Details

This function may produce negative option values when nonsensical values are used for a0, a1, and a2.

Value

call	call price
put	put price

Author(s)

Kam Hamidieh

References

D. Shimko (1993) Bounds of probability. *Risk*, 6, 33-47

E. Jondeau and S. Poon and M. Rockinger (2007): *Financial Modeling Under Non-Gaussian Distributions* Springer-Verlag, London

Examples

```
r      = 0.05
y      = 0.02
te     = 60/365
s0     = 1000
k      = 950
sigma  = 0.25
a0     = 0.30
a1     = -0.00387
a2     = 0.00000445
```

```
#
```

```

# Note how Shimko price is the same when a0 = sigma, a1=a2=0 but substantially
# more when a0, a1, a2 are changed so the implied volatilities are very high!
#

price.bsm.option(r = r, te = te, s0 = s0, k = k, sigma = sigma, y = y)$call
price.shimko.option(r = r, te = te, s0 = s0, k = k, y = y,
                    a0 = sigma, a1 = 0, a2 = 0)$call
price.shimko.option(r = r, te = te, s0 = s0, k = k, y = y,
                    a0 = a0, a1 = a1, a2 = a2)$call

```

sp500.2013.04.19

S&P 500 Index Options on 2013-04-19

Description

This dataset contains S&P 500 options with 62 days to expiration at the end of the business day April 19, 2013. On April 19, 2013, S&P 500 closed at 1555.25.

Usage

```
data(sp500.2013.04.19)
```

Format

A data frame with 171 observations on the following 19 variables.

```

bidsize.c call bid size
bid.c call bid price
ask.c call ask price
asksize.c call ask size
chg.c change in call price
impvol.c call implied volatility
vol.c call volume
openint.c call open interest
delta.c call delta
strike option strike
bidsize.p put bid size
bid.p put bid price
ask.p put ask price
asksize.p put ask size
chg.p change in put price
impvol.p put implied volatility
vol.p put volume
openint.p put open interest
delta.p put delta

```

Source

<http://www.cboe.com/DelayedQuote/QuoteTableDownload.aspx>

Examples

```
data(sp500.2013.04.19)
```

sp500.2013.06.24

S&P 500 Index Options on 2013-06-24

Description

This dataset contains S&P 500 options with 53 days to expiration at the end of the business day June 24, 2013. On June 24, 2013, S&P 500 closed at 1573.09.

Usage

```
data(sp500.2013.06.24)
```

Format

A data frame with 173 observations on the following 9 variables.

bid.c call bid price

ask.c call ask price

vol.c call volume

openint.c call open interest

strike option strike

bid.p put bid price

ask.p put ask price

vol.p put volume

openint.p put open interest

Source

<http://www.cboe.com/DelayedQuote/QuoteTableDownload.aspx>

Examples

```
data(sp500.2013.06.24)
```

`vix.2013.06.25`*VIX Options on 2013-06-25*

Description

This dataset contains VIX options with 57 days to expiration at the end of the business day June 25, 2013. On June 25, 2013, VIX closed at 18.21.

Usage

```
data(vix.2013.06.25)
```

Format

A data frame with 35 observations on the following 13 variables.

```
last.c closing call price  
change.c change in call price from previous day  
bid.c call bid price  
ask.c call ask price  
vol.c call volume  
openint.c call open interest  
strike option strike  
last.p closing put price  
change.p change in put price from previous day  
bid.p put bid price  
ask.p put ask price  
vol.p put volume  
openint.p put open interest
```

Source

<http://www.cboe.com/DelayedQuote/QuoteTableDownload.aspx>

Examples

```
data(vix.2013.06.25)
```


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