A
abscissae of the Legendre polynomials 255
adjusted \( J \) statistic (\( J^{Adj} \)) 5, 8–12, 10, 50, 51, 52, 54–69, 198, 199, 201–18
distribution of 53
serial autocorrelation of 211
American options 76
Anderson–Darling goodness-of-fit tests 239
Archimedean copulae 8, 173, 263
Asian financial crisis (1996) 63, 88
assets under management (AUM) 17
asymmetric dependence risk premium 49–71
conditional dependence patterns 54
data 50–1
distribution of \( J^{Adj} \) 53
empirical design 49–50
factor correlations 52
in-sample regression results 54–62
out-of-sample regressions 62–3
time-varying risk 63–70
asymmetric dependence, consistently measuring 7–12
asymmetric dependence, estimating in high dimensions 169–93
empirical application 181–92
comparison with conventional copula approach 191–2
data 181–3
estimates of pairwise copulas 186–8
estimates of compounding functions 188–90
estimates of univariate distributions 184–6
parameterizations 177–81
bivariate copulas 178–80
compounding functions 180
goodness-of-fit (GoF) testing 180–1
univariate distributions 177–8
sequential procedure 171–3
theoretical motivation 173–7
asymptotics 175–7
composite pseudo-likelihood and model averaging 173–5
asymmetric dependence, excess return prediction and 209–18
persistence of asymmetric dependence 209–13
data and method 210–11
lower-tail and upper-tail asymmetric dependence 211–13
serial autocorrelation of the \( J^{Adj} \) statistics 211
predictive power of 199–209
AUS equities 206
data and method 200–1
UK equities 206–9
US equities 201–3
US REITs 203–6
spillover effects 214–18
asymmetric returns (AR) models 276
automatic lag selection method (Newey and West) 50
autoregressive conditional heteroscedasticity (ARCH) model 77
average value-at-risk (AVaR) see expected shortfall (ES)

B
backtesting 160
Bartlett kernel 50
Basel III 90
basket call option 122
basket call spread 122–3
basket options 111, 122
basket put option 122
basket risk reversal 122–3
Bayesian information criterion 215
Bayesian model averaging and optimal forecast combination 174
Bernanke put 111
best-of/worst-of products 111
Black’s volatility leverage effect 114
Black–Scholes delta 28, 30
Black–Scholes model 78
Blest’s coefficients 228
Blest’s rank correlations 222, 226
Blest’s measures 231
Brownian motion 114

C
call-vs-call trade 117
canonical fundamental skew normal (CFUSN) distribution 153
finite mixture of 154–5, 155–6
linear transformation of 156–7
performance of 163
canonical fundamental skew t (CFUST) distribution 153
finite mixture of 154–5, 156
linear transformation of 157
performance of 163
canonical vine copulas 263–88
data 265–7
research method 267–73
multivariate probability modelling
268–72
canonical vine copula 270–1
Clayton Archimedean copula 268–70
marginals modelling 271–2
portfolio parameterization process 272
optimization of investor’s utility function 273
results 273–88
efficient frontier vs. CVaR 273–4
out-of-sample portfolio performance 275–6
descriptive statistics of portfolio strategies 276
economic performance 280–1
further analysis of time-series performance 283–8
portfolio re-balancing analysis 279
risk-adjusted performance 276–9
value-at-risk (VaR) backtests 281–3
capital asset pricing model (CAPM) 2, 62
beta 7, 8, 9, 48, 51, 199, 201, 203, 206, 209
censored bivariate normal distributions 30
classical goodness-of-fit tests 239
Clayton canonical vine copula (CVC) 263, 264, 265, 275, 287
with normal marginals (CVC-N) 275–6, 276, 281, 283
with skew-T marginals (CVC-S) 275–6, 281, 282, 283, 285, 286, 287
Clayton copula 3, 8, 173, 224, 225, 242, 249, 250, 263
Clayton standard copula (SC) 264, 275, 283
with normal marginals (SC-N) 275–6, 281
with skew-T marginals (SC-S) 275–6
Clayton strategy 242
Cochran and Cox t-test 144
Commodity Trading Advisor (CTA) market 17
composite likelihood methods 173
compounding function, copula-type 172, 173
conditional Clayton copula 239
conditional coverage likelihood ratio (CCLR) 281, 283
conditional Gumbel copula 239
conditional mean 238
conditional MECC model 239
conditional normal copula 239
conditional skewness 238
conditional tail expectation (CTE) see tail-conditional expectation (TCE)
conditional value-at-risk (CVaR) see expected shortfall (ES)
conditional variance 238
conditional variance dispersion spread 123
conditional variance swap strike 120
conditional variance swaps 120–1
constant relative risk aversion (CRRA) 221, 223
continuous mapping theorem 260
copula function parameters 7
copula-based measure of dependence 226
copula-based pseudo- or quasi-MLE 175
correlation computation in presence of censoring 30
correlation leverage effect 114
correlation swap strike 121
correlation swaps 111, 121
corridor variance swaps 120
Cramer–von Mises goodness-of-fit test 239
crash-put option 110

D
DAX index dispersion trading 116
d-dimensional Student-t distribution 170
deep out-of-the-money index options 62
Index

<table>
<thead>
<tr>
<th>Term</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>default spread (DS)</td>
<td>235</td>
</tr>
<tr>
<td>density pooling</td>
<td>174</td>
</tr>
<tr>
<td>derivative strategies to hedge AD</td>
<td>122–3</td>
</tr>
<tr>
<td>Dirac's delta function</td>
<td>256</td>
</tr>
<tr>
<td>disappointment</td>
<td>1–3</td>
</tr>
<tr>
<td>dispersion leg weighting</td>
<td>121</td>
</tr>
<tr>
<td>dispersion trading</td>
<td>116–20</td>
</tr>
<tr>
<td>disappointment aversion</td>
<td>2–5</td>
</tr>
<tr>
<td>Gul's representation of</td>
<td>3</td>
</tr>
<tr>
<td>Skiadas</td>
<td>2–5</td>
</tr>
<tr>
<td>distributions for prices, example</td>
<td>24–37</td>
</tr>
<tr>
<td>normal</td>
<td>24, 28–31</td>
</tr>
<tr>
<td>where strike equals mean: $k = \mu$</td>
<td>28–30</td>
</tr>
<tr>
<td>general</td>
<td>30–1</td>
</tr>
<tr>
<td>Pareto</td>
<td>24, 32–7</td>
</tr>
<tr>
<td>scale gamma</td>
<td>24, 31–2</td>
</tr>
<tr>
<td>symmetric distributions with $k = \mu$</td>
<td>27–8</td>
</tr>
<tr>
<td>uniform prices</td>
<td>24, 25–6</td>
</tr>
<tr>
<td>dividend–price ratio (DY)</td>
<td>235</td>
</tr>
<tr>
<td>Dodd–Frank</td>
<td>90</td>
</tr>
<tr>
<td>dotcom bubble, collapse of 63</td>
<td></td>
</tr>
<tr>
<td>double Pareto-lognormal distribution</td>
<td>32</td>
</tr>
<tr>
<td>downside beta</td>
<td>7</td>
</tr>
<tr>
<td>downside risk</td>
<td>12</td>
</tr>
<tr>
<td>DuBois–Reymond's lemma</td>
<td>256</td>
</tr>
<tr>
<td>d-univariate Student- $t$ marginals</td>
<td>170</td>
</tr>
<tr>
<td>Dupire's local volatility mode</td>
<td>125</td>
</tr>
</tbody>
</table>

E

Edgeworth expansions | 78 |
| EGARCH(1, 2) | 75, 76, 79 |
| corollary 4.1 | 80 |
| proof of 103 |
| corollary 4.2 | 80 |
| proof of 103–9 |
| estimating true parameter values | 83–9 |
| S&P 500 returns – normal distribution specification, EGARCH(1, 2) | 84 |
| S&P 500 – $t$-distribution specification, EGARCH(1, 2) | 85 |
| US 10yr Bond Returns | 87–9 |
| US 10yr bond returns – normal distribution specification, EGARCH (1, 2) | 87 |
| US 10yr bond returns – $t$-distribution specification, EGARCH (1, 2) | 88 |
| US equity returns | 83–6 |
| evaluating forecasting performance | 90–1 |
| literature survey | 76–9 |
| model specifications | 79–83 |
| contemporaneous correlation | 79 |
| existence of moments | 81–3 |
| lagged inter-temporal correlation | 79 |
| proof of theorem | 101–2 |
| simulation method and results | 91–7 |
| GARCH forecast error results: $\beta = 0.75$ | 95 |
| GARCH forecast error results: $\beta = 0.80$ | 94 |
| GARCH forecast error results: $\beta = 0.90$ | 93 |
| GARCH forecast error results: $\beta = 0.98$ | 92 |
| results | 91–7 |
| SV forecast error results: $\beta = 0.75$ | 96 |
| SV forecast error results: $\beta = 0.80$ | 95 |
| SV forecast error results: $\beta = 0.90$ | 94 |
| SV forecast error results: $\beta = 0.98$ | 93 |
| EGARCH(1,2) specification compared with EGARCH(1, 1) | 87 |
| relation | 1, 2 |
| empirical likelihood (EL) method | 239 |
| empirical examples | 43–5 |
| equality of variances test (Steel and Torrie) | 144 |
| equity/gold correlation | 111 |
| errors-in-variables problem | 50 |
| European options | 76 |
| Eurozone crises (2010) | 63 |
| ex-ante absolute volatility | 76 |
| exceedance correlations | 235, 269 |
| exceeding ratio (ER) | 160 |
| exchangeable copula | 171 |
| expectation-maximization (EM) algorithm | 153 |
| expected shortfall (ES) | 152, 157, 158, 263, 268, 273 |
| expected tail loss (ETL) see expected shortfall (ES) |
| exponentially weighted averages | 77 |
| extreme value theory | 7 |

F

factor copula approach | 170 |
| Falier–Gumbel–Mogernstern (FGM) copula | 230 |
| Fama–MacBeth approach | 62 |
| finite mixtures of multivariate normal (FM-MN) | 163 |
| performance of | 163–6 |
| F-tests of serial uncorrelatedness | 181 |

G

gamma swap fair strike | 119 |
| gamma swaps | 118, 119–20 |
| gamma-neutral dispersion | 121 |
| GARCH model | 75–97 |
INDEX

Gaussian copula 127, 270, 275
multivariate skew-T (MST) copula 127–8
Gaussian–Legendre quadrature method 254
Generalized ARCH model see GARCH model
generalized method of moments (GMM) 171, 176–7
‘generated regressor’ problem 193
Gideon and Hollister’s (1987) coefficient 228
Gini’s gamma 253
global financial crisis (2007/8) 63
global savings glut hypothesis 88
Granger-causality test 215, 216
growth stocks 223
Gumbel copula 224, 225, 242, 249, 250
Gumbel portfolio weights 245
Gumbel strategy 242
Gumbel–Hougaard d-copula 170

H
Hadamard (i.e., dot) matrix multiplication operator 128
hedging asymmetric dependence 110–31
correlation skew, models for 124–31
copula models 127–31
instantaneous correlation models 124–5
local correlation modelling 125–7
correlation skew, effect on portfolio choice 114–16
characteristics and model intuition 115
empirical observations 116
optimal portfolio incorporating stochastic correlation 114–15
equity correlation products 116–23
basket options 122–3
correlation swaps 121
derivative strategies to hedge AD 122–3
dispersion 116–21
worst-of options 121–2
implied correlation skew 111–14
heterogeneity and CTA market size 37–43
institutional demands 37–40
size of the option market 40–3
‘large’ incremental variance d^2 43
‘small’ incremental variance d^2 42–3
historical moving averages 77

I
idiosyncratic risk 12
implied correlation skew 112
inference for margins (IFM) method 272
inference function for margins (IFM) method 238
Integrated GARCH (IGARCH) model 81
Ito calculus 22
J
J statistic, adjusted see adjusted J statistic
Jacobi process 124

K
Kendall’s tau 253
Kolmogorov–Smirnov test 234
of marginal distributions 185
of uniformity 181, 184, 186
Kullback–Leibler cross entropy (KLCE) distance 222, 223
Kullback–Leibler divergence criterion 176

L
L’Hôpital’s rule 25, 42
Lagrangian multipliers 258
Langnau (2010) model 127
Lebesgue measure 256
Legendre orthogonal polynomials 254
Legendre polynomials, abscissae of 255
Leibnitz’s rule 24
leverage effect 77
likelihood ratio (LR) test statistic 162
Lipschitz constant 261
Lipschitz continuous function 174
Ljung–Box tests 186
log consumption–aggregate wealth (or human capital plus asset holdings) ratio (Cay) 235–6
log-hyperbolic distribution 32
log-normal Brownian motion 32
lower-tail asymmetric dependence (LTAD) 2, 3, 6–7, 12, 47, 49, 199

M
marginal conditional stochastic dominance (MCSD) framework 2
marginal utility of wealth 115
market model 19–20
equilibrium prices and portfolios 19–20
Markov independence test 160
matrix Riccati equations 115
maximum entropy (ME) principle 222
maximum likelihood estimator (MLE) 230
mean absolute error (MAE) 90, 91
mean mixed error-over (MME-O) 91, 96
mean mixed error-under (MME-U) 91, 96
mean-value theorem 260
mean–variance portfolio theory (MVPT) 269, 287
minimum mean square error (MMSE) forecast 96
misspecification 75–97
moments, computation of 20–4
comparison with Black—Scholes delta 22–3
option and stock 20–2
sign of $\omega_21$ 23–4
Monte Carlo simulation 146, 222, 238, 267, 273
mortgage-backed securities 18
most entropic canonical copula (MECC) 221–50
approximation error of density, simulation of 233–4
dynamic, estimation of 261–2
large sample properties of 232–3
maximum entropy and copulas 225–7
portfolio weights 245
strategy 242
most entropic copulas (MECs) 221, 222
as a bivariate distribution with uniform[0,1] marginals 227–32
multivariate normal distribution (MVN) 3, 4, 275, 276, 282, 283, 285, 286, 287
multivariate skew normal and skew t-mixture models 152–67
application to an Australian portfolio 160–6
data set 160
evaluation of risk measures 160–2
performance of fitted models 163–6
finite mixture of skew distributions 153–5
linear transformation skew normal and skew t-mixtures 155–7
risk measures 157–60
based on skew mixture models 158
skew normal mixture models 158–9
skew t-mixture models 159–60
multivariate skewed Student-t distribution 169

N
NAGARCH model 178, 181, 184
nesting condition 173
non-commercial traders 44
normal copula 224, 225, 242
normal distribution 24, 28–31
general 30–1
where strike equals mean: $k = \mu$ 28–30
normal portfolio weight 245

O
Omega ratio 276
CVC-S 279
Orstein–Uhlenbeck diffusion process 78
orthant normal probabilities 135
orthant probability-based correlation 133–46
characteristics of orthant correlations 136–9
orthant probabilities and orthant correlation 134–5
orthant probability testing 135–6
in presence of skewness and kurtosis 139–41
quantifying the complementarity of asset characteristics 141–5
over-hedging 120

P
Pacific Investment Management Company (PIMCO) 83
Paley–Zygmund inequality 27
Pareto distribution 24, 32–7
correlation and beta for 36–7
$p$-copula 178–9
Pearson’s correlation coefficient 221
Pearson’s product-moment correlation 133, 134
Pearson’s product-moment correlation coefficient 141, 145, 145f
percentage of failure likelihood ratio (PoFLR) 281, 282
pooled Sasabuchi (1988a) $t$-test 144
portfolio rebalance effect 89
price of asymmetric dependence 47–71
price–earnings ratio ($PER$), 235
probability integral transforms (PUT) 180
probability of shortfall (PS) 152
pseudo-copula 175
pseudo-maximum likelihood estimator (PMLE) 171

Q
quantitative easing 111
quasi-Newton algorithm 238

R
radially symmetric copula 171
random walk 77
realized variance 120
Reghai (2010) model 127
relative entropy (RE) 221–2
restricted skew normal distribution 154
rolling-window approach 267
INDEX

root mean square error (RMSE) 90
Russian default (1990s) 88

S
scoring rules 175
semiparametric approach 228
sequential copula-based pseudo-MLE 174
Shannon entropy 222, 223, 225, 227, 228
Sharpe ratio 86, 244, 276, 279, 287
Sheppard’s (1898, 1899) theorem of median
dichotomy 135
   extensions 150–1
      proof of application of 148–50
simplicity, principle of 229
skew normal distribution 153
skew t-distribution 153, 154
skew-t-NAGARCH model 184
Sklar copula 225–6
Sklar theorem 223, 228
   conditional 237
Slutsky’s theorem 260
Sortino ratio 276, 279, 287
Spearman’s rank correlation 226
Spearman’s rho 226, 253
standard Wald restriction test 84, 85
standardized score function 226
stochastic volatility (SV) models 75–97
straddle dispersion 117–18
Student t copula 173
   multivariate 270
Student t distribution 275
   multivariate 179
   multivariate skewed 169
Student-t d-copula 170
Student-t marginals 170, 272, 275
style investing 223
swap dispersion 118
symmetric copula 171

T
tail-conditional expectation (TCE) 152, 157,
   158, 159–60, 163, 165
tail-risk management 63–4, 110
tail-risk trades 110
tail value-at-risk (TVaR) see tail-conditional
   expectation (TCE)
Taylor expansion 119
term spread (TS) 235
TGARCH model 224, 238
theta-neutral dispersion 121
trading volatility 117–20

U
unconditional coverage test 160
univariate skewed Student t (Skew-T) 271, 275
unpooled Satterthwaite (1946)-style t-test 144
upper-tail asymmetric dependence (UTAD) 2, 7,
   47, 48, 49, 199

V
Vale–Maurelli (1983) implementation of
Fleishman’s (1978) method 139
value stocks 223
Value-at-Risk (VaR) 48, 76, 152, 157–8,
   273
vanilla put option 111
Vanna 117
variance notional 118
variance swap 118
variance swap strike 118
variance swaps dispersion 118–19
vector autoregression (VAR) model 199, 216
Vega 117
vega-neutral dispersion 121
vine copulas 170
volatility convexity (vol-of-vol) 118–19
volatility skew 78
volatility swaps 118, 119
Volga 117
vol-of-vol 118–19

W
Watson goodness-of-fit test 239
Wharton Research Data Services
(WRDS) 50
Wishart process 114, 115
worst-of call 121–2
worst-of options 121–2
worst-of put 122

Z
Zhang goodness-of-fit tests 239