```
credit risk models 170-1, 179-80
2-dimensional consistent semi-martingale copula
     213 - 14
                                                       definitions 32–3, 78–9, 170–1, 190,
2-dimensional semi-martingale copula 213-14
2-increasing requirement of copula functions
                                                       Kendall function 33-4, 142-52, 184-5
     12-47, 77
                                                     ARMA model 5-6
                                                     Asian options 125–6
absolutely continuous 43–5, 82–3, 111–13, 166,
                                                     asset allocations 1-2, 4, 181-206
                                                       see also capital..
ABSs see asset-backed securities
                                                     as et classes, types 2-3
ABX credit indices 160
                                                     asset and liability management (ALM)
active fund managers 193-202
                                                          181 - 2
  see also asset managers
                                                       see also Value-at-Risk
actuarial science 23, 170
                                                     asset managers 1-2, 121, 181-206
                                                       HM 195-202
additive processes 121
                                                       market-neutral funds 201-2
aggregation functions
  C-convolutions 187–9, 191–3, 194–202
                                                       performance attribution analysis 194-202
                                                       problems 1–2
  concepts 122-5, 179-80, 181, 185-206,
                                                       real-world asset management 1–2, 121,
     210-12
                                                          181-206
alpha 121
                                                       returns 193-202
  see also excess returns
                                                       risk management 193-202
alternative investments 153-4, 204-6
                                                       semi-parametric models 200-2
  see also hedge funds; private equity funds
                                                       VaR 194-5
Altiplanos 124-5, 126, 130-2, 148-50
                                                     asset prices
  see also barrier . . . ; European . . .
                                                       see also pricing
  with memory features 130-2
                                                       dynamics 49-89, 102-7, 121, 127-52
AND/OR long-short correlation rule 27–9,
                                                     asset swaps 154–5
     124
                                                     asset-backed securities (ABSs) 156–8
appendices 215-43
                                                     asymptotic analysis 62, 102-10, 163-4, 170-2,
arbitrage 2-3, 4, 15-16, 28, 88-9, 132-3, 137-8,
                                                          211 - 12
     148-52, 153-4, 163
                                                     asymptotic independence 62, 211-12
  see also regulatory . . . ; triangular . . .
                                                     asymptotic normality 102–10
arbitrage-free approach to pricing 2–3, 4, 15–16,
                                                     at-the-money options (ATM) 16
     88-9, 132-3, 148-52
                                                     atoms 43
Archimedean copulas 31-4, 35-8, 78-9, 92-3,
                                                     attachment of the tranche 157
     103-7, 111-19, 123-52, 170-1, 179-80,
                                                     attribution concepts 186–7
     184-5, 189-93, 199, 210
                                                     autocorrelations 49, 63, 113-16
  see also Clayton . . . ; copula functions;
                                                       see also autoregression models; correlation . . .
    Frank . . . ; Gumbel . . .
                                                       definition 49
```

260

JWBK526-Cherubini

autoregression models 5-8, 93-9 see also ARMA . . . ; GARCH . . . ; VARMA... linear QAR models 93 non-linear quantile autoregression 93–9

Bachelier model of stock price movements 49-50

Banach spaces 228-9, 236-7 see also convergence . . . banks 1, 153-80, 182-3

Index

see also credit . . . ; debt . . . capital adequacy requirements 182-3 global financial crisis from 2007 1, 153, 161-2

barrier Altiplanos 126, 148-50 barrier options 125-6, 142-4

base correlation

see also correlation skew

definition 163

Basel I agreements 153-4

basket credit derivatives 29, 121, 156-7 see also first-to-default . . . ; nth-to-default . . .

definition 156

basket equity derivatives 25-6, 29, 121, 123-5 137 - 52

basket equity notes 123-5

basket options 151-2

Bayes' theorem 27, 39-40

Bayesian Information Criterion (BIC) 173

Beare, 2009 theorem 111–13

BEKK (Baba, Engle, Kraft, and Kroner) specification 7

benchmarks, asset managers 200-2

bespoke CDOs 160

see also collateralized debt obligations

best-of options, copula applications 28-9

between dependence, definition 36

Bielecki et al, 2008 approach 212-14

binary options see digital options

binomial distributions 219-20

see also distributions

Black-Cox approach 160, 161-3

Black-Scholes options pricing formula 30, 160-3

Bologna school 49

bonds 2, 123–32, 150–2, 154–5, 158–9, 160–3,

see also corporate . . . ; debt . . . ; government . . .

constrained level curves 193

level curves 190-3

risk capital management 183-206

seasoned/on-the-run bonds phenomenon 202 - 3

bootstrapping 128, 159-60, 179-80

Borel sets 55-8, 83-6, 215-16, 234-5

bottom-up models

see also capital allocations; copula . . . ;

marginal distributions

definition 4, 186

Bouyè and Salmon, 2009 theorem 92-3

Brownian copulas 63-89, 133-4

Brownian covariance matrices 238-40

Brownian motion 59–89, 129–30, 133–52, 161-3, 207-10, 224, 236-7, 238-40,

see also diffusion; Lévy processes; random

walks; Wiener process

CEV clock 64-6

definition 239

FGM copula 67

geometric Brown an motion 140-1, 161-3

Markov processes 59, 133-52, 236-7

scaling properties 239

self-similar copulas 59–60, 67

semi-martingales 64, 133–5

stable processes 60, 76–7

time-changed Brownian copulas 63-6, 129-30, 133-7

VG clock 65-6, 140-1

buckets 2-3

see also risk management

C-convolutions 8–9, 67–89, 116–19, 134–6, 177-80, 187-9, 191-3, 194-202, 203-6

aggregation functions 187-9, 191-3, 194-202, 203-6

asset managers 194-202

concepts 67-77, 116-19, 134-6, 187-9,

191-3, 203-6

copula-based Markov processes 116

definition 67-9

densities 72-3

dynamic analysis of credit risk portfolios 177 - 80

examples 70-5, 78-9

likelihood function of Markov processes

116-19

Markov processes 116–19

private equity funds 206

propagation 73-5

risk capital management 187-9, 191-3,

194-202, 203-6

simulations 72-3

square-root formula 203-6

temporal aggregation 203-6

c-quantile regression 91-3

cadlag trajectories 231-3

calibration 5, 122-52

call options	Chen and Fan, 2006 93, 99–107
see also options	chi-plots 33–4
copula applications 23–4, 33–4, 36–8, 122–52, 161–80	chi-square laws with n degrees of freedom distributions 222–3
put-call parity 23-4, 26, 28-9, 157	see also gamma
callability clauses, values 34	chi-squared estimators 109-10
canonical decomposition 42–5, 212–14, 241–3	Clayton copula 17–19, 26, 32–4, 36–9, 70–5, 78,
see also semi-martingales; special semi-martingales	81–3, 86, 92–9, 102–7, 113, 115–16, 117–19, 123–5, 134–6, 142–4, 147–52, 171,
definition 241	179–80, 184–5, 189–93, 199, 205–6
canonical representations 42–5, 82–3, 212–14	see also Archimedean; copula functions
see also copula densities	definition 32–3, 78
capital adequacy requirements, banks 182–3	risk capital management 184–5, 189–93, 199,
capital aggregation 181, 185–206, 210–12	205–6
see also top-down models	closed-end funds 202–6
asset managers 194–202	closure property 79, 234
C-convolutions 187–9, 191–3, 194–202,	closure of the tensor product 214
203–6	cluster analysis 172-6
concepts 181, 185–93, 194–202, 210–12	co-copulas 28–9
definition 181, 185–6, 191	co-integrated systems 6
temporal aggregation of risk measures 202–6	collateralized debt obligations (CDOs) 156–60,
capital allocations 1–2, 4, 181, 185–206	178-80
see also asset; bottom-up models	definition 156–8
bond portfolios 189	pricing 157–8
concepts 181, 185–93	synthetic CDOs 157–60
constraints 191–5	commodities markets 158–9
definition 181, 185–6, 191	common stochastic trends 6
level curves 189–93	compatibility 2–9, 14–19, 35–8
Cauchy distributions 224, 228–9	see also marginal distributions; risk-neutral
see also distributions	measures
CDOs see collateralized debt obligations	definition 2
CDSs see credit default swaps	compensators, definition 242
CDX credit index	
concepts 160, 163, 177–80	complex-valued integrals 222–3 compound digital options 34
term structures 177–80	
centered normal distribution with covariance	compound Poisson processes 239, 240 see also Poisson; subordinators
see also multivariate normal distributions	
definition 226	comprehensive copulas 33, 61–2
central limit theorem 110–13, 181	conditional copulas 45–6 see also dynamic
CEV see constant elasticity of variance	•
· · · · · · · · · · · · · · · · · · ·	conditional densities 44–5, 100–7, 108–10 conditional expectations 39–42, 187–206,
CGMY (Carr, Geman, Madan, and Yor) processes 240	229–30
*	definition 229–30
see also Lévy	
Channan Volmogorov agystion 51, 66, 225	properties 230
Chapman–Kolmogorov equation 51–66, 235	conditional independence 40–2, 51–89, 141,
see also Markov processes; transition	147–52
functions	conditional probabilities 39–42, 45–6, 51–89,
definition 51–2, 55–8, 235	141–52, 162–4, 170–1, 188–206
characteristic exponent 227–8, 238–40	see also factor copulas
characteristic function 76–7, 219, 222–6,	definition 27, 39–40, 216
237–40	conditional pseudo-copulas 47
see also Fourier transform; multivariate	conditional sampling 62–3, 72–3, 93–9
distributions	confidence levels, VaR 182–4, 186–206
definition 76–7, 219, 222–3	consistency concepts 102–10, 175–6, 213–14
moments 219	constant elasticity of variance (CEV) 64–6

JWBK526-Cherubini

continuous time stochastic processes 50-89, 121-52, 207-14, 231 see also additive ...; Lévy ...; random walks definition 231 discrete time convergence issues 207 contour complex integration techniques 141, 223 convergence in distribution on in law, definition 228-9 convergence in probability, definition 228-9 convergences of sequences of random variables 100-7, 228-9 see also vague . . . ; weak . . . convex functions 230 see also Jensen's inequality convolution concepts 8-9, 67-89, 116-19, 133, 134-6, 141-52, 177-80, 187-9, 191-206 see also C-convolutions cophenetic correlations 175 cophenetic distances 175 copula densities 42-5, 52-66, 72, 82-3, 108-10, concepts 42-5, 52-3, 108-10, 113 definition 42-3 copula functions 1-2, 4-9, 11-47, 49-89. 93-119, 121-52, 177-80, 184-206, 207-14 see also Archimedean . . . ; bottom-up models, Clayton . . . ; elliptical . . . ; empirical . . . ; \(Frank . . . ; Fréchet family . . . ; Gaussian . . . Gumbel...; joint distribution...; marginal distributions; mixture . . .; student's . . . absolutely continuous copulas 43-5, 82-3, 111-13, 166, 229 applications 14-47, 49, 91-119, 121-52, 171, 179-80, 184-206, 207-14 asset managers 196-202 asset price dynamics 49–89, 102–7, 121, 127 - 52basic concepts 11-47 Brownian copulas 63-89, 133-5 challengers 7 concepts 1-2, 4-9, 11-47, 207-14 convolution concepts 8-9, 67-89, 116-19, 133, 134-6, 141-52, 177-80, 187-9, 191-206 correlation trading 121-52 critique 4-5, 8, 49 Cuadras-Augé copula 167-9 definition 1, 4-5, 7, 11-14 discrete time processes 50-89, 128-9, 207 DNO copula/Markov-processes links 51-66, 67, 70, 81–3, 86–9, 127–30, 132–3, 207 dynamic copulas 45-7, 91-119 econometrics 49, 91-119 exchangeability properties 34–5 factor copulas 39-42 Farlie-Gumbel-Morgenstern copula 23

frontier issues 207–14 future prospects 207-14 hierarchical copulas 35-8 HM copula 196-202 Lévy copula 207-10, 213-14 limitations 8, 49 Markov chain simulations 62-3, 76 Markov processes 50-66, 67, 70, 75-89, 93-119, 121-52, 207-14 Marshall-Olkin copula 36, 43-5, 113, 165-9 martingales 50, 66-89, 127-30, 207-14 mixing properties 100-7, 110-13 multivariate credit products 4, 9, 29, 153-80 multivariate equity derivatives 89, 102-7, 121 - 52non-linear quantile autoregression 93-9 non-parametric estimation 91, 108–10 Pareto copula 210-12 product operators 52-8, 127-30, 137 quantile regressions 91–3 requirements 12-14 risk capital management 184–206 risk-neutral pricing restrictions 132-3, 140-1 self-similar copulas 58–62, 67, 82–3 semi-martingale copula 207, 212–14 semi-parametric estimation 91, 93, 99–107, 136-7, 200-2 state of the art 11-47 time-changed Brownian copulas 63-6, 129-30, 133-7 types 13-14, 17-19, 29-33 uses 4-5, 6, 11-47, 49, 50-89, 91-119, 121-52, 171, 179-80, 184-206, 207-14 vine copulas 44-5 volatility trading 121-52 volume between two points 24–6 core satellite strategies 201-2 corporate bonds 183-4 see also bonds correlation 1-9, 15-16, 121-52, 162-3, 166-7, 181-206 see also implied . . . ; Pearson . . . ; Spearman's . . . products 1, 15-16 trading 1, 15-16, 121-52 correlation risks 1-9, 181-206 definition 1 leverage effects 2-3 pricing 1-3 correlation skew 163 see also base correlation correlation smiles 163 correlation swaps 121, 144-6 see also swaps corridors 18-19 coupons 123-52

covariance matrices 7, 207–10, 214, 225–6, 238-40 covariances 7, 20, 79, 109-10, 207-10, 214, 225-6, 238-40 see also Pearson correlation measure definition 20 covenants in debt contracts 161-3 credit default swaps (CDSs) 154-5, 158-60 credit risk information sources 158-60 definition 154-5 credit derivatives 4, 9, 29, 153-80 see also basket . . . ; multivariate . . . pricing 4, 9, 29 term structures 9 credit events 153-80 see also multivariate credit products credit information 158-60 credit portfolio analysis 172-80 credit products 9 credit risk 153-80, 182-3, 202-6 see also default probabilities; recovery rates Black-Cox approach 160, 161-3 bootstrapping uses 159-60, 179-80 C-convolutions 177–80 concepts 153-8, 202-6 correlation skew 163 credit portfolio analysis 172–80 Cuadras-Augé copula 167-9 definition 164 dynamic analysis of credit risk portfolios 176-80 frailty models 170-1, 172 Gaussian copula 161-3, 169 granularity adjustments 171-2 hedging 160 implied correlation 162-3 indices 160, 177-80 information sources 158-60 intensity-based models 164-9 Marshall-Olkin copula 165-70 Merton's 1974 quasi-debt-to-firm-value ratio 161 - 2model types 158-80 Moody's KMV model 158-60, 161 multivariate models 155-8, 160-80 put options 160-3 regulations 153-4 scoring models 158-60 structural approach 158-60 structured credit risk models 160-4, 179-80 term structures 159, 165, 176-80 transfer finance concepts 153–8 univariate credit transfer products 154-5 univariate models 154-5, 160-1, 165 unsupervised clustering techniques 172-6 Vasicek formula 163-4, 171, 179-80

credit risk portfolios, dynamic analysis 176–80 CreditRisk 172 cross-derivatives of copulas, copula density factors 42-5 cross-section dependence 5, 49, 94–9, 102–7, 122-52, 179-80 Cuadras-Augé copula 167-9 see also Marshall-Olkin copula cumulative distribution functions 17-18, 36-8, 46-7, 67-8, 76-7, 82-3, 140-1, 216, 224-5 curse of dimensionality 4 curse of linearity 8 d-increasing property 207-8 data compression methods 7-8 see also factor analysis; principal components data generating processes (DGPs) 93-9, 116-19 DCC model 7–8 DD see distance-to-default De Morgan formula 215 debt finance 2, 123–32, 150–2, 153–80, 183–206 sce aiso banks; bonds; credit . . . decay rates 100-7, 111-13 detault events 153-80, 189-93 see also credit risk default probabilities 158–80, 182–206 see also credit risk bootstrapping uses 159-60, 179-80 term structures 159, 178-80 definite integrals, definition 217 degrees of freedom 30, 81-3, 93-9, 222-3 Deheuvels' empirical copula 14 delta hedging multivariate digital products 16-19, 141-52 tranches 157-8 deltas 16-19, 141-52 dendrograms (cluster trees) 175-6 see also hierarchical correlation models dependence functions see copula functions dependent increments 49, 67, 78–83, 85–6, 132-5, 204-6 extraction processes 81-3 Markov processes 49, 67, 78-83, 85-6, 132-5 simulations 81, 85–6 derivatives 2-3, 4-5, 9, 14-19, 21-2, 23-4, 26–9, 33–5, 36–8, 121–52, 153–80, 181–2 see also credit . . . ; forward . . . ; futures; multivariate equity . . . ; options; swaps characteristic function 219 complexities 2–3 definitions 121-2 pricing 4-5, 9, 14-19, 21-2, 23-4, 26-9, 33-5, 36-8, 121-52, 157 detachment of the tranche 157, 163 see also credit risk

DGPs see data generating processes	dynamic models, trends 1–9
difference stationary, definition 6	dynamic processes 1–9, 16–19, 28–9, 45–7,
diffusion 50, 214	49–89, 91–119, 121–52, 176–80
see also Brownian motion	dynamics of asset prices 49–89, 102–7, 121,
digital best-of options, copula applications 28-9	127–52
digital options	
see also Altiplanos	econometrics 5, 8–9, 49, 89, 91–119, 121–52
copula applications 14–19, 21–2, 23–4, 26,	copula applications 49, 91–119
28–9, 33–4, 121–2, 124–5, 128, 130–2,	cross-section dependence 5, 49, 94–9, 102–7
141–52	dynamic processes 49, 91–119
definition 124–5	quantile regressions 91–3
Dirac delta function 242	VAR models 5
directional trading see alpha	economic capital 182
discount functions, memory features 130–2	see also margins
discrete time stochastic processes 50–89, 128–9,	economic time 133–4
207, 231	efficient market hypothesis (EMH) 50-89, 127
continuous time convergence issues 207	see also Markov processes
definition 50, 73–4, 231	efficient markets (-2, 9, 50–89, 127
distance-to-default (DD) 158, 161	eigenvectors 7-8
see also KMV model	elliptical cooulas
distribution of losses, term structures 176–80	see also copula functions; Gaussian;
distributions 1, 30–2, 135, 153, 210–14, 216–18,	siliant's t
219–26, 237–40	concepts 29–31, 79–81, 113–16, 153, 162–3,
see also binomial; exponential;	204–6
gamma; Lévy; marginal;	definition 30–1
moments; multivariate; normal;	EMH see efficient market hypothesis
Pareto; Poisson; stable;	EMMs see equivalence martingale measures
student	empirical copula 14, 36–8, 97–107
Cauchy distributions 224, 228–9	see also copula functions
infinitely divisible distributions 226 -8, 237–40	equal P almost surely, definition 216
inverse Gaussian distributions 224	equal u-almost everywhere functions, definition
marginal cumulative distributions 225	215–16
types 30–2, 219–26	equity notes 123–5
diversification 153–4, 181 - 206	equity products 2, 9, 89, 102–7, 121–52, 158–60
DNO copula/Markov processes links 51–66, 67,	see also derivatives; multivariate
70, 81–3, 86–9, 127–30, 132–3, 207	equity tranches 156–7, 163, 178–80
see also copula functions; Markov processes	equity-linked notes 155–6
concepts 51–63, 67, 70, 81–3, 86–9, 132–3,	equivalence, definition 229
207	equivalence martingale measures (EMMs) 2–3,
definition 51-2, 55-8, 86-9	15–16, 24
multivariate Markov processes 86–9, 127–30,	ergodic processes 99, 111–13
207, 214	Erlang laws distributions 222–3
dollar/euro exchange rates 3	see also gamma
dollar/yen exchange rates 3	estimation issues 43–5, 91, 93–119, 136–7,
domain of attraction, definition 210–12	200–2
Doob closure property 234	MLE 43-5, 101-7
down barrier options 125–6, 142–4	non-parametric estimation 91, 108–10
drift 140–1, 238, 240, 242–3	semi-parametric estimation 91, 93, 99–107,
dual of a copula 28–9	136–7, 200–2
dynamic analysis, credit risk portfolios 176–80	Euclidean distance 173, 174–6
dynamic copulas 45–7, 91–119	see also Minkowski
see also conditional ; pseudo	Euler attribution principle 186–7
definition 45–6	euro/dollar exchange rates 36–9, 142–4
quantile regressions 91–3	euro/pound exchange rates 17–18, 36–9
dynamic hedging 16–19, 28–9, 141–52	euro/yen exchange rates 3, 17–18, 36–9
see also delta hedging	euro/yuan exchange rates 36–9, 142–4

European Altiplanos 148–50	Fisher transform 11, 23–4
European multivariate equity derivatives 122–52	see also probability integral transformation
see also multivariate equity derivatives	FOREX markets 3, 9, 17–19, 36–9, 142–4
Eurostoxx 50 index 14–19, 23–4, 26, 28–9,	forward prices 132–3, 136
204–5	Fourier transform 50, 219
Eurostoxx 100 index 124–6, 204–5	see also characteristic function
Everest notes 124, 150	fractionally integrated processes, definition 6
excess returns 121–52	frailty models 170–1, 172
see also alpha	Frank copula 32–3, 70–5, 78–9, 96–9, 102–7,
exchangeability properties 34–5	111–13, 115–16, 118–19, 171, 177–80,
exercise dates 14–19, 122–52	184–5, 189, 191–3
expected excess returns 121–52	see also Archimedean ; copula functions;
expected shortfall (ES) 2–3	Gaussian
expected utility problems 1–2	definition 32–3, 78–9
expected values 217–18, 229–30	risk capital management 184–5, 189, 191–3
see also conditional expectations; moments	Fréchet bounds 16, 21–2, 93–4
expiry dates 122–52	Fréchet family of copula: 13–14, 16, 21–2, 52–5,
exponential distributions 135, 221, 222	62
see also distributions	see also maximal; minimal; product
extra reading 251–7	applications 15, 21–2, 62
extreme events 27, 40–2	definition 13–14
see also fat-tails	self-singuar copulas 62
extreme value theory, domain of attraction	Fréchet-Floeffding bounds 93–4
210–12	frontier topics 1, 34–5, 207–14
	FT3E 100 26, 102–7, 119
factor analysis 7–8	Fubini's theorem 53
factor copulas 39–42, 162–3	funded synthetic CDOs
see also conditional probabilities	see also synthetic CDOs
fair games 230 fair strike 135–6 fair value 135–6 Fama Fluene 50	definition 158
fair strike 135–6	future prospects, copula functions 207–14
fair value 135–6	futures 158–9, 181–2
Tuma, Eugene 30	C 1: 1: 1 C : 2007 ::
Farlie–Gumbel–Morgenstern copula (FGM) 23,	Gagliardini and Gourièroux, 2007 proposition
60–3, 67, 82–3, 85–6, 111–13	109–10
Brownian copula 67 definition 23	gamma distributions 32–3, 65–6, 136, 140–52,
	222–3, 227–8, 239–40
self-similar copulas 60–3, 67, 82–3	see also chi-square laws ; distributions;
fat-tails 27, 30–1, 91–119, 184–206, 218 <i>see also</i> extreme events; leptokurtosis;	Erlang laws definition 32, 222–3
student's t distributions	gamma processes 65–6, 140–52, 239–40
definition 27, 218	see also variance
FGM see Farlie–Gumbel–Morgenstern copula	definition 239–40
filtered probability spaces, definition 232	GARCH models 7–8
filtrations 47, 50–89, 132–3, 138, 168–9,	see also multivariate ; orthogonal
212–14, 231–7, 241–3	Gaussian copula 30–2, 41–2, 59–60, 79, 80–1,
see also information; natural;	92–3, 102–7, 111–13, 115–16, 118–19,
predictable; stochastic processes	122–5, 142–4, 147–52, 161–3, 169
concepts 47, 50, 87–9, 138, 212–14, 231–3	see also copula functions; elliptical;
Cuadras–Augé copula 168–9	Frank
definition 50, 232	credit risk models 161–3, 169
financial markets 1–9, 49, 91, 113–14, 181–206	critique 161–2
correlation risks 1–9, 181–206	definition 30–1, 41, 79, 80–1
trends 1–2, 113, 121	implied correlation 162–3
finite measures 212–14, 215	self-similar copulas 59–60
first-to-default options/swaps 29, 155–7	Gaussian distributions <i>see</i> normal distributions
see also swaps	general integrals, definition 217

JWBK526-Cherubini

generalized inverse, definition 11–12, 182–3 geometric averages, copulas 35 geometric Brownian motion 140-1, 161-3 German banks 169 global financial crisis from 2007 1, 153, 161–2 government bonds 154-5, 183-94 see also bonds Granger causality 89, 137-8 see also H-condition Granger-independent increments 89, 137–8 granularity adjustments 171-2 grounded requirement of copula functions 12-47, 60-89 Gumbel copula 33, 36-8, 78, 113, 171, 179-80, 211 - 12see also Archimedean . . . ; copula functions definition 33, 78 H-condition 89, 137-8 see also Granger causality Hadamard derivative 109-10 harmonic mean, definition 168-9 hazard rates 170-1 see also frailty models hedge funds 153-4, 200-6 hedging 1, 16-19, 24, 28-9, 137-8, 141-157–60 see also delta . . . ; dynamic . . . ; risk management; static . . . credit risk 160 multivariate equity derivatives 141 52 portfolios 17-19, 137-8 tranches 157-8 Heisenberg paradox 192 Helinger measure of dependence 113-14 Henriksson–Merton model (HM) 195–202 hierarchical copulas 35–8 hierarchical correlation models 175-6 see also dendrograms (cluster trees) histograms 70-2, 143-4 historical simulations 3, 21–2, 62–3 HM see Henriksson-Merton model HM copula 196-202 homogenous portfolios 163-9, 172-6, 183-4, 186-206, 212 *I*-margin of *F*, definition 209–10 I-marginal tail integral, definition 209–10 IBOXX index 183-4 Ibragimov DNO extension 86-8 Ibragimov and Lentzas, 2009 theorem 114-15 IFM (inference functions for margins) method 8, 43 - 4implied correlation 3, 24, 162-3 credit risk 162-3 critique 162-3

definition 3, 162-3 estimates 4 FOREX markets 3 Gaussian copula 162–3 implied volatilities 3, 24, 30, 162 in-the-money options (ITM) 16, 24 inconsistency coefficients 175-6 independent increments, Markov processes 49, 67, 70-2, 75-7, 83-6, 88-9, 132-3, 137-52 index options 26 index of stable distributions 223-4 infinite measures 215 infinitely divisible distributions 226-8, 237-40 see also gamma . . . ; Lévy . . . ; Pareto . . . ; Poisson . . . ; stable . . . information processes 50, 108–10, 121, 147–52, 158-60 see also filtration; credit information 158-60 **EMH 50** innovation 50, 66-89, 121, 133-4, 147-52 see also shock demition 50 institutional investors 153-4, 202-6 see also insurance companies; mutual funds; pension funds insurance companies 153-4 integer-valued random measures 242 integration 216-26 intensity-based credit risk models 164-9 see also Cuadras-Augé copula; Marshall–Olkin copula; Poisson processes interest rate risk 157-8 interest rate swaps 154, 157-8 intrinsic value of options 16, 24 see also at-the-money . . . ; in-the-money . . . ; out-of-the-money . . . inverse functions 11-12, 182-3 inverse Gaussian distributions 224, 225 see also distributions; normal... Italian BTPs 154–5, 183–94 Italian default probability term structure 159 ITraxx credit index 160 Jacobians 225 Jensen's inequality 230 see also convex functions joint default probabilities 160-80, 189-93 joint distribution function 1–9, 11–47, 91–119, 162-3, 197-202 see also copula . . . ; marginal . . . joint log-likelihoods 101-7 joint normal distributions 30-1

jumps 50, 63-4, 141, 208-14, 231, 238-40

see also Poisson processes

junior tranches 156

```
K-means 172–3
Kallsen and Tankov, 2006 approach 207-12
Kendall function 16, 17-18, 21-2, 31, 33-4,
     36-8, 70-2, 115-16, 135, 142-52, 166-7,
     178–80, 184–5, 189, 200–2, 204–6
Klüppelberg and Resnick approach 210-12
KMV model 158-60, 161
  see also distance-to-default
Kohonen self-organizing maps 174-5
kth-order Markov process 49, 86–9
kth-variate Markov process 49, 86–9
kurtosis 218
  see also leptokurtosis; moments
lack of memory property 221
  see also exponential distributions
Laplace transform 32, 170-1, 218-19
  see also moment-generating function
law (distribution) of X 216
law of large numbers 163, 229
learning rules, Kohonen self-organizing maps
     174 - 5
Lebesque measures 42–3, 93–4, 108–10, 215
  see also Radon . . .
leptokurtosis 218
  see also fat-tails; kurtosis
level curves 189–93
leverage effects 2-3
  see also correlation . . . ; volatilities
Lévy copula 207-10, 213-14
Lévy measure 209-14, 227-8
Lévy processes 64, 121, 139, 207–10, 227–8.
     237 - 40
  see also Brownian motion; CGMY . . . ;
     gamma...; Markov ... Poisson...;
     stochastic..
  definitions 64, 207-8, 237-40
  pure jump Lévy processes 213-14
  subordinators 64, 240
Lévy-Ito decomposition theorem 238-40
Lévy–Khintchine theorem 50, 227–8, 237–40,
  see also infinitely divisible distributions
  definition 50, 227-8, 237-8
  multivariate version 228
LGD see loss given default
likelihood function 43–5, 101–7, 116–19
  see also maximum likelihood estimation
  C-convolution-based Markov processes
     116-19
linear correlation 19-20
  see also correlation . . . ; Pearson correlation
    measure
linear mapping 109-10
linear QAR models, non-linear quantile
    autoregression 93
```

```
linearity 21-2, 214, 217
liquidity risk 202-6
local martingales 234, 241-3
  see also martingales
locally finite measures 215
  see also Radon measures
log-likelihoods 116–19
log-prices 116-19, 122-52
log-returns 1-2, 50, 91-119
long assets 2–3
long correlation 1, 2-3, 27-9, 150-2
long memory 6, 108-9, 113-16
long positions, CDSs 158
long volatilities 2–3
long-range dependence, concepts 5-6
lookback options 125
loss given default (LGD) 156-7, 164
lower tail index 27, 33
Luciano-Schouters model 139-41
macroeconomic analysis see market timing
     anai /si3
Mahalanobis distance 173
managers see asset managers
mapping processes 2–3
  see also risk management
margin calls, futures 182
marginal cumulative distributions 225
  see also distributions; multivariate . . .
marginal distributions 2–9, 11–47, 57–8, 66–89,
     93-119, 122-52, 184-206, 209
  see also compatibility; copula...; joint...
  concepts 2-3, 4-5, 11-14, 20-2, 57-8, 184,
     198-202
  HM copula 198-202
marginal risk 181
margins
  see also economic capital
  futures 182
mark-to-market prices 14-19, 182
market co-movements
  copula applications 14-16, 34-5, 40-2
  frontier issues 34-5
market risk 182-3, 202-6
market timing analysis, asset managers 195-6,
     201 - 2
market-neutral funds, asset managers 201–2
Markov chains, copula simulations 62–3, 76,
     93-8, 115-16
Markov copula 207-14
Markov processes 5, 49–89, 93–119, 121–52,
     207-14, 234-7
  see also Lévy . . . ; stable . . . ; stochastic . . .
  Brownian motion 59, 133–52, 236–7
  C-convolution-based Markov processes
```

116-19

Markov processes (Continued) maximal copula 13, 53–5 see also copula functions; Fréchet family . . . canonical representations 82-3, 212-14 construction techniques 56–8 maximized expected utility 1-2 copula functions 50-66, 67, 70, 75-89, maximum likelihood estimation (MLE) 43-5, 93-119, 121-52, 207-14 101 - 7definitions 50, 51-2, 86-8, 93-113, 235-7 see also estimation . . . dependent increments 49, 67, 78-83, 85-6, sieve MLE 101-7 132 - 5maximum of prices in baskets DNO copula/Markov-processes links 51-66, see also rainbow options 67, 70, 81–3, 86–9, 127–30, 132–3, 207 definition 124 Maximum Probable Loss (MPL) frontier issues 207-14 independent increments 49, 67, 70–2, 75–7, see also Value-at-Risk 83-6, 88-9, 132-3, 137-52 historical background 181-2 likelihood function generated by the mean reversion 64-6, 206 C-convolution 116–19 mean squared errors (MSEs) 103-7 martingales 66-89, 127-30, 207-14 mean-variance 1-2, 6 mixing properties 100-7, 110-13 means 1-2, 6, 64-6, 193-7, 118-19, 122-52, multivariate Markov processes 86-9, 127-30, 172-3, 212 207, 214 measurable sets definition 215 measurable space, definition 215 non-linear quantile autoregression 93-9 non-parametric estimation 91, 108–10 measure theory 215–16, 241–2 pricing 121-52 memory features, definition 130-2 product operators 52, 55-8, 127-30, 137 Merton's 1974 quasi-debt-to-firm-value ratio semi-group of operators 236–7 161-2semi-parametric estimation 91, 93, 99–107, mezzanine tranche 156–8, 163 microeconomic analysis see stock picking stationary copula-based Markov process 93 min function, definition 125–6 102-7, 108-10, 116-19, 122-52 minimal copula 13, 53-5 stationary increments 116-19 see also copula functions; Fréchet family . . . symmetry requirements 127-8 minimum chi-squared estimators 109-10 Markov property 51 minimum of prices in baskets 124 Marshall-Olkin, 1988 algorithm 170-1 see also rainbow options Marshall-Olkin copula 36, 43-5, 113, 165-70 Minkowski distance metrics 173 see also Cuadras-Augé copula see also Euclidean . . . martingales 2–3, 4–5, 9, 15, 49–89, 127–30, mixing decay rates 100-7, 111-13 207-14, 233-4, 249-3 mixing properties 100–7, 110–13 mixture copula 13-14, 21-2, 58-62, 85-6 see also local . . . ; semi . . . ; stochastic see also copula functions processes; submartingales; supermartingales asymptotic independence 62 copula functions 50, 66-89, 127-30, definition 13-14, 62 207 - 14MLE see maximum likelihood estimation definitions 83-6, 233-4 model risk 4, 180 modular mathematical models 1 Doob closure property 79, 234 forward prices 132-3 see also copula functions Granger causality 88-9, 137-8 moment-generating function 218-26 H-condition 89, 137–8 see also Laplace transform Markov processes 66-89, 127-30, 207-14 moments 1, 112-13, 121, 217-26 multivariate settings 88-9 see also distributions; expected values; pricing 4, 9, 15, 88–9, 127–30, 137–52 kurtosis; skewness; variance; volatilities problems 83-6, 133-5 characteristic function 219 restrictions 88-9, 137 definition 217-18 Matlab 25-6 'moneyness' 16, 24 matrices 7-8, 80-1, 225-6 see also at-the-money . . . ; in-the-money . . . ; see also covariance . . . ; multivariate out-of-the-money . . . monotonicity 52-3, 93-4, 100-7, 150-2, 162-3, distributions; vectors max function, definition 125-6 188-9, 217

JWBK526-Cherubini

```
off-balance sheet transactions 153-4
on-the-run bonds, seasoned bonds
    202 - 3
open-end mutual funds 153-4, 202-6
operation risk 182–3, 202–6
options 5, 14-30, 33-5, 36-8, 121-52, 157,
     160-80, 196-202
  see also basket . . . ; call . . . ; derivatives;
    digital . . . ; intrinsic value . . . ; multivariate
    equity derivatives; put . . .
  Asian options 125–6
  Black-Scholes options pricing formula 30,
  delta hedging 16-19, 141-52
  pricing 14-19, 21-2, 23-4, 26-30, 33-5,
    36-8, 121-52, 157, 160-3
  rainbow options 124-5, 147-52
  spread options 122-4, 147, 150-2, 162-3,
    164
originate-to-distribute products 153
Ornstein-Uhlenbeck process 64–5
orthogonal GARCH model 7-8
out-of-the-money options (OTM) 16, 33
overview of the book 8–9
panel data models 49
Pareto copula 210–12
Pareto distributions 210-12, 224
  see also distributions
partial differential equations 40–2, 44–5, 51–2,
    92-3, 187-8
path-by-path continuous part of the quadratic
    variation process, definition 241
path-dependent contracts, definition
     122
path-dependent equity derivatives 122,
    125 - 52
  see also Asian ...; barrier ...; lookback ...;
    running maxima; running minima
  definition 122, 125-6
  semi-parametric pricing models 136-7
  types 125-6
payoff functions 121-52, 160-80
  see also derivatives
Pearson correlation measure 20-2, 114, 166-7,
     168
  see also covariances; linear correlation
pension funds 153-4
performance attribution analysis 194-202
persistence shock property 6, 113-16
Poisson and Cox processes, credit risk models
     165-6
Poisson distributions 4, 211–12, 213–14, 220,
    227, 239
```

see also distributions

definition 220

```
Poisson processes 164–9, 211–12, 213–14, 239,
    240
  see~also~compound\ldots; intensity-based credit
    risk models; jumps; subordinators
  definition 164, 239, 240
portfolios 1-2, 4, 121-52, 153-80, 181, 185-206
  asset allocations 1-2, 4, 181-206
  asset managers 193-202
  capital aggregation 181, 185-206, 210-12
  capital allocations 1–2, 4, 181, 185–206
  credit portfolio analysis 172-80
  dynamic analysis of credit risk portfolios
  homogenous portfolios 163–9, 172–6, 183–4,
     186-206, 212
  risk capital management 2-3, 34, 181-206
  unsupervised clustering techniques 172-6
  VaR 2-3, 34, 181-5, 186-206
  Vasicek formula 163-4, 171, 179-80
positive quadrant dependence (PQD), definition
    15-16
PQD see positive quadrant dependence
predictable filtrations 232
prices, multivariate equity derivatives 121–52
pricing 2–9, 14–47, 49, 57–8, 121–52, 156–80
  arbitrage-free approach to pricing 2–3, 4,
     15–16, 132–3
  Black-Scholes options pricing formula 30,
     160 - 3
  CDOs 157-8
  correlation risks 1–3
  credit derivatives 4, 9, 29
  definition 2-3
  derivatives 4-5, 9, 14-19, 21-2, 23-4, 26-9,
     33-5, 36-8, 121-52, 157
  FOREX markets 17-19, 36-8, 142-4
  index options 26
  martingales 4, 9, 15, 88-9, 127-30, 137-52
  Monte Carlo simulations 123-5, 147-52
  multivariate credit products 156-80
  multivariate digital products 14–16, 21–2,
    23-4, 26, 28-9, 33-5, 36-8, 128, 141-52
  multivariate equity derivatives 14-16, 21-2,
    23-4, 26, 28-9, 33-5, 36-8, 121-52
  multivariate/univariate product arbitrage
    issues 2-3, 15
  options 14-19, 21-2, 23-4, 26-30, 33-5,
    36-8, 121-52, 157, 160-3
  path-dependent derivatives 136-52
  problems 2-3, 122, 133-5
  real-world asset management 2-3, 121
  risk-neutral pricing restrictions 132–3, 140–1
  semi-parametric pricing of path-dependent
    derivatives 136–7
principal components analysis 7-8
private equity funds 153-4, 204-6
```

```
probability 11-47, 51-89, 109-10, 158-60, 164,
                                                     random walks 49-50, 128-30
     181-206, 215-30
                                                        see also Brownian motion; continuous time . . .
  see also distributions
                                                     rank correlation see Spearman's rank correlation
  concepts 158-60, 181-206, 215-30
                                                     reading 245-57
                                                     real-valued functions 56-8, 87-8, 110-13, 241-2
  default probabilities 158–80, 182–206
  elements of probability 215-30
                                                     real-valued random variables 56-8, 87-8,
  survival probability 23, 159-60, 161-3
                                                          110-13, 216
probability density functions 109-10, 164,
                                                     real-world asset management 1-3, 121, 181-206
     188-9, 198-202, 215-26
                                                     realized correlation 3-4
probability integral transformation 11-47, 51-89
                                                     recovery rates
  see also copula functions
                                                        see also credit risk
  definition 11, 29-30
                                                        credit events 158-60, 164-9
probability space, definition 215-16
                                                     recursions of running maxima/minima 126-32,
product copula 13, 52-8, 61-2, 64, 150-2
                                                          138 - 41
  see also copula functions; Fréchet family . . .
                                                     reduced-form models see intensity-based credit
  definition 13
                                                          risk models
                                                     references 245-9
product operators, DNO
     copula/Markov-processes links 52-8, 67,
                                                     reflection principle 127-9
     70, 127-30, 137
                                                        see also running...
profits and losses, temporal aggregation 203-6
                                                     regular vines, definition 44–5
                                                     regulatory arbitrage 153-4
protective put options 196, 200
pseudo-copulas
                                                     relative entropy 114
  see also dynamic . . .
                                                     returns 1-9, 50, 91-119, 121-52, 183-206
  definition 46-7
                                                        asset managers 193-202
pseudo-random numbers 70-2
                                                        excess returns 121–52
pure jump Lévy processes 213-14
                                                        log-returns 1–2, 50, 91–119
  see also semi-martingales
                                                        normal distributions 1–2
                                                     risk 1-9, 33-4, 49, 108-10, 121, 141-52,
put options 14-19, 21-2, 33-5, 122-
     160-3, 196-202
                                                          153-80, 181-206
  see also options
                                                        see also credit . . . ; liquidity . . . ; market . . . ;
  copula applications 14-19, 21
                                                          operation . . .
     122-52, 157
                                                        appetites 154
  credit risk 160-3
                                                        concepts 1-9
put-call parity 23-4, 26, 28-9,
                                                        diversification 153-4, 181-206
                                                        interest rate risk 157-8
QAR see quantile autoregression
                                                        real-world dimensions 2–3, 121, 153–4,
                                                          181-206
quadratic variation processes 65–6, 137, 241–3
quantile autoregression (QAR), non-linear
                                                        systemic risks 156
     quantile autoregression 93-9
                                                     risk management 1-9, 33-4, 49, 108-10,
quantile of a distribution 182-3
                                                          141-52, 153-80, 181-206, 210-12
quantile regressions, dynamic copulas 91-3
                                                        see also buckets; correlation risks; expected
                                                          shortfall; hedging; historical simulations;
radial symmetry 24, 29, 60-3, 80-1, 84-6, 92-3,
                                                          mapping processes; stress testing;
     128
                                                          Value-at-Risk
Radon measures 211-12, 215-16, 227
                                                        asset managers 193-202
                                                        C-convolutions 187–9, 191–3, 194–202,
  see also Lebesque . . . ; locally finite . . .
Radon-Nikodym derivative 2-3, 229
rainbow options 124-5, 147-52
                                                        capital aggregation 181, 185-206, 210-12
  see also maximum . . . ; minimum . . .
                                                        capital allocations 181, 185-206
random measures 212, 241-3
                                                        concepts 1-9, 33-4, 49, 108-10, 153-80,
random times 137, 232
                                                          181-206, 210-12
random variables 8-9, 91-3, 216, 228-9
                                                        definition 2-3, 181-5
  convergences of sequences 228-9
                                                        HM 195-202
  definition 216
                                                        level curves 189-93
random vectors 224-6
                                                        non-linear dependence between risks 108-10
  see also multivariate distributions
                                                        private equity funds 204-6
```

23:37

risk management (Continued)	shock 6, 50, 156–7, 181–206
problems 2–3, 183–4, 186	see also innovation
real-world asset management 2-3, 121,	short assets 2–3
181–206	short correlation 1, 2–3, 27–9, 152
semi-parametric models 200-2	short memory processes, long memory processes
square-root process 202-6	113–16
temporal aggregation of risk measures 202-6	short volatilities 2–3
risk-free rates 1–2, 15–16, 23–4, 29, 34, 156–7,	sieve MLE 101–7
161–3, 195–202	simulations
risk-neutral measures 2–3, 15–16, 131–3, 140–1,	C-convolutions 72–3
156–7, 161–3	dependent increments 81, 85–6
see also compatibility	historical simulations 3, 21–2, 62–3
definition 2, 15	Markov chain simulations 62–3, 76, 93–8,
pricing restrictions 132–3, 140–1	115–16
running maxima 125-32, 138-41	Monte Carlo simulations 102–7, 123–5,
see also path-dependent equity derivatives	147–52
running minima 125–32, 138–41	stationary copula based Markov process 93-8.
see also path-dependent equity derivatives	102–7, 108–10, 122–52
	singular copulas, definition 43, 166
S&P 500 index 14–19, 23–4, 28–9, 123–6	skewness 24, 163, 184–5, 218, 223–4
Samuelson, Paul 50	see also correlation ; moments;
scaling properties, Brownian motion 239	volatility
scatter plots 95-6, 102-7, 184	Sklar, Abe 4–5
Schönbucher formula, definition 171	Strar theorem 12–14, 23, 31, 35, 46–7, 141, 209
SCODMY model 5–6, 137, 139–41, 144–52	see also copula functions
see also semi-parametric models	definition 12–14
scoring models, credit risk 158–60	SOMs see self-organizing maps
seasoned Asian option 126	spatial dependence 5, 49, 91, 121–2, 178,
seasoned bonds, on-the-run bonds 202–3	181–206
securitization 156–8, 177–80	Spearman's rank correlation 16, 20–2, 31, 167,
see also asset-backed securities; collateralized	169
debt obligations	Spearman's rho 22–3
self-organizing maps (SOMs) 174–5	special purpose vehicles (SPVs) 156–8
self-similar copulas 58–62 C7, 82–3	see also securitization
semi-group of operators 236–7	special semi-martingales 241–3
semi-martingale copula 207, 212–14	see also canonical decomposition
definition 207, 212–14	speculation 1, 4, 49–50
Lévy copula 213–14	spread options 122-4, 147, 150-2, 162-3, 164
semi-martingales 64, 133–7, 207, 212–14, 240–3	SPVs see special purpose vehicles
Brownian motion 64, 133–5	square-root process 64-5, 102-3, 202-6
definitions 240–3	definition 64–5, 202–3
frontier issues 207, 212–14	private equity funds 206
pure jump Lévy processes 213–14	risk management capital 202-6
time-changed Brownian motion 64, 133-7	stable copula 60, 76–7
semi-parametric models 5–6, 66, 91, 93, 99–107,	stable distributions 76-7, 79, 223-4, 227, 239-40
136-7, 139-41, 144-52, 200-2	see also distributions
applications 102-7, 136-7, 200-2	definition 76–7, 223–4, 239
asset managers 200–2	index 223–4
copula-based Markov processes 91, 93,	stable processes 60, 76–7
99–107, 136–7	see also Markov
definition 5–6, 91, 99–100, 136–7	state of the art, copula functions 11–47
path-dependent equity derivatives 136-7	static hedging 24, 141
risk capital management 200-2	stationary copula-based Markov process 93-107.
SCODMY model 5-6, 137, 139-41, 144-52	108–10, 116–19, 122–52
semi-unsupervised cluster analysis 172-3	definition 93, 99
seniority of debt 154, 156–7, 178–80	simulations 93-8, 102-7, 108-10, 122-52

transition functions 55-8, 112-13, 116-19, 235 - 7triangular arbitrage 3 trigger events, memory features 130–2 turbulence 181-206 underlying assets 5-26, 121-52, 160-80 see also derivatives unfunded synthetic CDOs 158, 160, 177-80 see also CDX . . . ; synthetic CDOs uniform marginals requirement of copula functions 12-47 unit roots 6, 108-10 univariate credit risk models 154-5, 160-1, 165 univariate credit transfer products 154-5 univariate probability theory 2–3, 5, 12–13, 15, univariate product pricing, multivariate product arbitrage 2-3, 5, 15-19, 23-4, 26 unsupervised clustering techniques, concepts 172 - 6unwinding periods, VaR 182-4, 202 up barrier options 125-6 upper tail index 27, 33 see also survival copulas utility function 1-2 vague convergence 229 Value-at-Risk (VaR) 2-3, 34, 181asset managers 194-5 critique 2-3, 181-5 definition 2, 181-4 historical background 181-2 homogeneity property 183-4, 186-206 insurance policies 188–9 Kendall function 34 level curves 190-3 multivariate VaR 186-206 square-root formula 203-6 unwinding periods 182-4, 202

VaR homogeneity property 183–4, 186–206

VaR see Value-at-Risk; vector autoregression

variance 1-2, 6, 7-8, 64-6, 118-19, 121,

122-52, 218-26, 240, 242-3 see also moments; volatilities

CEV 64-6 definition 218 variance gamma processes (VG) 65-6, 140-1, see also Brownian motion; gamma... Brownian copulas 65-6, 140-1 definition 65-6, 140, 240 variance swaps 121, 134-6 see also swaps VARMA model 6 Vasicek formula 163-4, 171, 179-80 vector autoregression (VAR) 5 vector independent increments 88-9, 138-41 vectors 24-6, 224-6 see also matrices; random . . . venture capital 204-6 versions of conditional expected values, definition 230 VG see variance gamma processes Vidozzi A., 2009 approach 212-14 vine copclas, definition 44–5 volatinties 1, 2-9, 24, 121-52, 162, 163 se also implied . . . ; variance . . . volatility skew 24, 121, 163 definition 24 trade-the-skew strategy 121 volatility smiles 21-2, 24, 147-52, 163 volatility swaps 121, 134-6 see also swaps volatility trading 121-52 volume, definition 14, 207-8 volume between two points, copula functions

waterfalls 156-8 see also securitization weak convergence 228-9 white-noise disturbances 163 Wiener process 64-6 see also Brownian motion Williamson transform 32–3 within dependence, definition 36

zero-coupon bonds 160-3

Index compiled by Terry Halliday