Acknowledgements page x			<i>page</i> xxiii		
Syn	nbols d	and Abbreviations	XXV		
Pai	rt I Tl	he Foundations			
1	What This Book Is About				
	1.1	My Goal in Writing This Book	3		
	1.2	What My Account Leaves Out	5		
	1.3	Affine Models	6		
	1.4	A Simple Taxonomy	8		
	1.5	The Choice of Variables	10		
		1.5.1 Latent versus Observable Variables	10		
		1.5.2 The Spanning Problem	15		
		1.5.3 The Constraint Problem	16		
	1.6	Why Do We Need No-Arbitrage Models After All?	19		
	1.7	Stamp Collecting and Shallow versus Deep Explanations	20		
	1.8	The Ideal Reader and Plan of the Book	21		
2	Defir	24			
	2.1	The Purpose of This Chapter	24		
	2.2	The Building Blocks	24		
		2.2.1 Arbitrage	24		
		2.2.2 Pseudo-Arbitrage	25		
		2.2.3 Sharpe Ratios	27		
		2.2.4 Bond Prices and Yields	28		
		2.2.5 Duration and Convexity	31		
		2.2.6 Forward Rates	32		
	2.3	Log Prices and Log Returns	33		
	2.4	Dimensional Analysis	34		

\$

	2.5	Annen	dix 2A: Vectors and Matrices	36
	2.0	2.5.1	Definition	36
			Transformations of Vectors	37
		2.5.3		38
		2.5.4		39
		2.5.5		40
	2.6		dix 2B: Mean-Reverting and AR(1) Processes	41
	2.0	2.6.1	The Ornstein–Uhlenbeck Process	41
		2.6.2		42
		2.6.3		
			Ornstein–Uhlenbeck Process	43
	2.7	Appen	dix 2C: Some Results from Stochastic Calculus	44
		2.7.1	Ito's Lemma	44
		2.7.2		45
		2.7.3		46
			The Ito Isometry	47
		2.7.5	Risk-less Portfolios	48
3	Links	among	Models, Monetary Policy and the Macroeconomy	49
_	3.1	-	arpose of This Chapter	49
	3.2		onetary Channels	50
	3.3		lelling Framework	52
	3.4		onetary Actions: A Simple Model	56
	3.5		ating Reduced-Form Models	58
		3.5.1	General Considerations	58
			Assessing the Quality of the Calibration Process	60
		3.5.3	State Variables versus Model Parameters	61
4	Bonds	s: Their	Risks and Their Compensations	63
	4.1		rpose of This Chapter	63
	4.2		al Rates, Inflation and Real Rates: A Qualitative	
		Discus		64
		4.2.1	Inflation Risk	64
		4.2.2	Real-Rate Risk	65
		4.2.3	Putting the Pieces Together	66
	4.3	Real-V	Vorld and Risk-Neutral Probabilities: The Market	
		Price c	of Risk	68
		4.3.1	Introducing the \mathbb{P} and \mathbb{Q} Measures	69
		4.3.2	Introducing the Market Price of Risk	72
	4.4	An Im	portant First Result: Bond Prices as Q-Expectations	76
	4.5		ice Process and Its Expectations	77
		4.5.1	The General Case	77

		4.5.2 The Affine Case	78
	4.6	Nominal Rates, Inflation and Real Rates: Definitions	79
5	The F	Risk Factors in Action	81
	5.1	The Purpose of This Chapter	81
	5.2	Expectations and Risk Premia during an Important Market	
		Period	81
		5.2.1 An Account of What Happened	81
		5.2.2 Possible Explanations of What Happened	85
	5.3	How Can We Estimate Risk Premia?	87
	5.4	Different Types of Risk Premia	88
	5.5	What Are Investors Compensated For?	91
		5.5.1 Decomposition of the Risk Premium	91
		5.5.2 'Which' Liquidity Are TIPS-Investors	
		Compensated For?	93
	5.6	What Is and What Is Not a True Risk Premium	94
	5.7	Does It Matter if a Risk Premium Is 'Really' a Risk	
		Premium?	96
6	Princ	ipal Components: Theory	98
	6.1	The Purpose of This Chapter	98
	6.2	What Are Principal Components?	98
		6.2.1 The Axis Rotation	98
		6.2.2 The Signal and the Noise	103
	6.3	How Many Principal Components Do We Need for Yields?	103
	6.4	First Conclusions	104
	6.5	Some Mathematical Results	105
7	Princ	ipal Components: Empirical Results	108
	7.1	The Purpose of This Chapter	108
	7.2	Nominal Rates	108
		7.2.1 Descriptive Features	108
		7.2.2 Mean-Reverting Properties – Each PC in Isolation	112
		7.2.3 The Joint Mean-Reverting Behaviour of Principal	
		Components	116
	7.3	Real Rates and Break-Even Inflation	122
	7.4	Correlation between Nominal, Inflation and Real Principal	
		Components	128
	4 TT 75	he Dwilding Dieslage A. Fingt I. ook	

Part II The Building Blocks: A First Look

8	Expectations			
	8.1	The Purpose of This Chapter	137	

	0.0	T Solation The second state that BY A 1 to	107
	8.2	Linking Expectations with No-Arbitrage	137
		8.2.1 A One-Factor World	138
	0.0	8.2.2 Moving to Many Factors	141
	8.3	An Example: A Mean-Reverting Process for the Short Rate	143
	8.4	Expectations and Survey Data	145
9	Conv	exity: A First Look	147
	9.1	The Purpose of This Chapter	147
	9.2	Where Does Convexity Come from?	147
	9.3	The Links between Convexity and Jensen's Inequality	149
		9.3.1 A Special but Important Case: Gaussian Random	
		Variables	150
	9.4	What Does Convexity Depend On?	152
	9.5	Why Convexity Is Different	154
	9.6	Why Isn't Convexity 'Always Good'?	156
	9.7	Who Sets the Price of Convexity? A Bit of Story-Telling	157
10	A Pre	eview: A First Look at the Vasicek Model	160
	10.1	The Purpose of This Chapter	160
	10.2	The Vasicek Model	161
	10.3	Properties of the Vasicek Model	161
		10.3.1 Distributional Properties of the Vasicek Model	161
		10.3.2 Bond Prices in the Vasicek Model	165
		10.3.3 The Duration in the Vasicek Model	165
		10.3.4 Yield Volatilities in the Vasicek Model	168
	10.4	Rate Expectations and the Shape of the Vasicek Yield Curve	168
	10.5	Convexity in the Vasicek Model	170
		10.5.1 An Expression for Convexity	170
		10.5.2 Convexity and the Volatility of Yields	171
		10.5.3 How Big Should One Expect the Convexity Effect	
		to Be?	172
		10.5.4 What Is the 'Right' Reversion Speed?	173
	10.6	The Risk Premium in the Vasicek Model	175
	10.7	The Functional Form of the Market Price of Risk	176
	10.8	The Link between the Market Price of Risk and the Sharpe	
		Ratio	178
	10.9	Appendix 10A: Proof that	
		$r_t = \{e^{-\kappa(t-t_0)}\}r_0 + \{1 - e^{-\kappa(t-t_0)}\}\theta + \int_0^t e^{-\kappa(t-s)}\sigma_r dz_s$	181

Part III The Conditions of No-Arbitrage

11 No-Arbitrage in Discrete Ti		rbitrage in Discrete Time	185
	11.1	The Purpose of This Chapter	185

	11.2	Type-I Arbitrage	186
	11.3	Bounds to the Price-Correction Term: Type-I	
		Arbitrage	188
	11.4	Bounds to the Price-Correction Term: Type-II	
		Arbitrage	189
	11.5	A Useful Rewriting	192
	11.6	Extension to Many Factors	193
	11.7	The Task of the Long-Term Bond Investor	195
12	No-A	rbitrage in Continuous Time	196
	12.1	The Purpose of This Chapter	196
	12.2	Constructing a Risk-Less Portfolio: The Market Price of	
		Risk Again	196
	12.3	Interpretations of the Market Price of Risk	199
	12.4	Excess Returns	200
	12.5	What the Market Price of Risk Can Depend On	201
	12.6	Appendix 12A: The Market Price of Risk and Excess	
		Return with Many Factors	202
13	No-A	rbitrage with State Price Deflators	206
	13.1	The Purpose of This Chapter	206
	13.2	A Bird's Eye View of the 'Traditional' and 'Modern'	
		Approaches	207
	13.3	Pricing Assets: The Building-Blocks Approach	208
	13.4	A Beautiful Result: The Change of Measure	211
		13.4.1 Prices as Expectations in the Risk-Neutral	
		Measure – Again	211
		13.4.2 The Equivalence of the State-Price Deflator and the	
		Stochastic Discount Factor	213
	13.5	The Process for the State-Price Deflator	214
	13.6	Special Assets: Discount Bonds	216
	13.7	Deriving the Drift of the State-Price Deflator	216
	13.8	The Short Rate Again	218
	13.9	Deriving the Volatility of the State-Price Deflator	219
		13.9.1 Evaluation of the Three Terms	220
		13.9.2 The Link between the Volatility of the State-Price	
		Deflator and the Market Price of Risk	221
		13.9.3 Where Does the Volatility of Bonds Come from?	222
		13.9.4 Summary of Results	223
14	No-A	rbitrage Conditions for Real Bonds	224
	14.1	The Purpose of This Chapter	224
	14.2	The Expression for the Real State-Price Deflator	224

xii **Contents**

	14.3	The Process for the Real State-Price Deflator	226
	14.4	The Link between Break-Even Inflation and Inflation	
		Expectations	229
		14.4.1 Inflation Expectation Under \mathbb{P}	230
		14.4.2 Inflation Expectation under \mathbb{Q}	232
		14.4.3 Inflation Expectation under \mathbb{T}	233
		14.4.4 Inflation Expectations under Different Measures	234
	14.5	The Risk Premium as a Covariance	235
	14.6	Moving to an Affine World	238
	14.7	The Market Price of Inflation Risk – Affine Models	239
15	Links	with an Economics-Based Description of Rates	241
	15.1	The Purpose of This Chapter	241
	15.2	First Derivation of the SDF	242
	15.3	From the SDF to Risk Premia	245
	15.4	Real versus Nominal Prices	248
	15.5	Idiosyncratic Risk	249
	15.6	The Links between the SDF and the Risk-Less Rate	250
		15.6.1 The No-Uncertainty Case	251
		15.6.2 Reintroducing Uncertainty	252
		15.6.3 But Does It Work?	253
	15.7	SDFs in Continuous and Discrete Time	256
	15.8	A More General Result for the Sharpe Ratio	257
Par	rt IV S	Solving the Models	
16	Solvi	ng Affine Models: The Vasicek Case	263
	16.1	Purpose of This Chapter	263
	16.2	The Replication Approach to Solving for Bond Prices: The	
		Vasicek Model	264
		16.2.1 The PDE Satisfied by Bond Prices	264
	16.3	A Special Case: Affine Term Structures	266
	16.4	The Vasicek Case	269
	16.5	Affinity of the Vasicek Model under $\mathbb P$ and under $\mathbb Q$	271
	16.6	Observations about the Solution	272
		16.6.1 Yields	272
		16.6.2 The Volatility Structure	273
		16.6.3 Forward Rates	273
		16.6.4 Calibrating to the Volatility Structure: Factorization	276
		16.6.5 Fitting to the Yield Curve	277
	16.7	Why Do We Care about a Humped Volatility Curve?	281
	16.8	How to Lengthen the Short Blanket	282

17	First I	Extensior	18	285
	17.1	The Pur	pose of This Chapter	285
	17.2	Affine M	Iodels with Many State Variables	285
		17.2.1	The $N = 2$ Case	287
		17.2.2	An Expression for the Variance for Generic N	288
		17.2.3	Stability	290
		17.2.4	Changing Variables	291
	17.3	Multiva	riable Exponentially Affine Models	292
	17.4	General	Properties of the Solutions	293
		17.4.1	Yields and Forward Rates	293
		17.4.2	Distributional Properties	294
	17.5	Appendi	ix 17A: Derivation of the Variance of a	
		One-Dir	nensional Mean-Reverting Process	295
	17.6	Appendi	ix 17B: Derivation of the Variance of a	
		Multidir	nensional Mean-Reverting Process	296
	17.7	Appendi	ix 17C: Stability of the Mean-Reverting System	297
18	A Ger	neral Pric	cing Framework	299
	18.1	The Pur	pose of This Chapter	299
	18.2	What Is	an Affine Model?	300
	18.3	The General Strategy		
	18.4	Summar	ry of the Equations Derived in Appendix 18A	303
	18.5	Various	Additional Results	304
		18.5.1	Expression for the Yield	304
		18.5.2	Expression for the Yield Covariance Matrix and	
			the Yield Volatilities	305
		18.5.3	Expression for the Volatility of the Instantaneous	
			Forward Rates	306
	18.6	Derivation of the Mean and Variance of the State Variables		
	18.7	Now We	e Have Solved (Almost) Any Affine Model	309
		18.7.1	Simple Vasicek	309
		18.7.2	The Doubly-Mean-Reverting Vasicek Model	310
		18.7.3	The Trebly-Mean-Reverting Vasicek Model	311
		18.7.4	The Stochastic-Market-Price-of-Risk Model	312
	18.8	Appendi	ix 18A: Solving for $\vec{B}(\tau)$ and $A(\tau)$	313
		18.8.1	Solving the ODE for $\vec{B}(\tau)$	314
		18.8.2	Solving the ODE for $A(\tau)$	316
	18.9	Appendi	ix 18B	323
		18.9.1	The Meaning of e^A	323
	18.10	Explicit	Calculation of the Formal Solution $\overrightarrow{x}_t = e^{At} \overrightarrow{x}_0$	324
		18.10.1	The Up-and-Down Theorem	325
		18.10.2	Commutation Relationships for A and $f(A)$	326

		18.10.3 Time Derivative of e^{At}	327
		18.10.4 Integral of e^{At}	327
		18.10.5 Evaluation of the Integral $\left[\int_0^T e^{-\mathcal{L}\tau} M e^{-\mathcal{L}\tau} d\tau\right]$	328
19	The S	Shadow Rate: Dealing with a Near-Zero Lower Bound	329
	19.1	The Purpose of This Chapter	329
	19.2	Motivation: Why the Shadow Rate Matters	330
	19.3	How the Shadow Rate Affects the Whole Yield Curve	332
	19.4	The Modelling Approach	333
		19.4.1 The Setting	333
		19.4.2 An Approximate Solution	334
	19.5	Does It Matter?	339
		19.5.1 The Shadow and Short Rates Compared	339
		19.5.2 The Effect of the Shadow Rate on Long Yields	339
		19.5.3 Sensitivity of the Results to the Floor Level	343
	19.6	A Broader View of the Topic	343
Par	rt V T	he Value of Convexity	
Par 20			351
		alue of Convexity	351 351
	The V	Value of Convexity The Purpose of This Chapter	
	The V 20.1	alue of Convexity	351
	The V 20.1 20.2	Value of Convexity The Purpose of This Chapter Break-Even Volatility – The Vasicek Setting	351
	The V 20.1 20.2	Value of Convexity The Purpose of This Chapter Break-Even Volatility – The Vasicek Setting Problems with the Vasicek Version of the Break-Even Volatility	351 351
	The V 20.1 20.2 20.3	Value of Convexity The Purpose of This Chapter Break-Even Volatility – The Vasicek Setting Problems with the Vasicek Version of the Break-Even Volatility Generalizing to Many Factors	351 351 355
	The V 20.1 20.2 20.3	Value of Convexity The Purpose of This Chapter Break-Even Volatility – The Vasicek Setting Problems with the Vasicek Version of the Break-Even Volatility Generalizing to Many Factors 20.4.1 Calculating the Terms $\vec{c}_1, \vec{c}_2, \vec{c}_3$ and \vec{c}_4	351 351 355 357
	The V 20.1 20.2 20.3	Value of Convexity The Purpose of This Chapter Break-Even Volatility – The Vasicek Setting Problems with the Vasicek Version of the Break-Even Volatility Generalizing to Many Factors 20.4.1 Calculating the Terms $\vec{c}_1, \vec{c}_2, \vec{c}_3$ and \vec{c}_4	351 351 355 357
	The V 20.1 20.2 20.3	Value of Convexity The Purpose of This Chapter Break-Even Volatility – The Vasicek Setting Problems with the Vasicek Version of the Break-Even Volatility Generalizing to Many Factors 20.4.1 Calculating the Terms $\vec{c}_1, \vec{c}_2, \vec{c}_3$ and \vec{c}_4 20.4.2 Expressing the Convexity in Terms of Yield	351 351 355 357 360
	The V 20.1 20.2 20.3 20.4	 Value of Convexity The Purpose of This Chapter Break-Even Volatility – The Vasicek Setting Problems with the Vasicek Version of the Break-Even Volatility Generalizing to Many Factors 20.4.1 Calculating the Terms c c c c c c 20.4.2 Expressing the Convexity in Terms of Yield Volatilities 	351 351 355 357 360 362
	The V 20.1 20.2 20.3 20.4	 Value of Convexity The Purpose of This Chapter Break-Even Volatility – The Vasicek Setting Problems with the Vasicek Version of the Break-Even Volatility Generalizing to Many Factors 20.4.1 Calculating the Terms c i, c i, c i, c <lii, <="" c="" li=""> </lii,> 20.4.2 Expressing the Convexity in Terms of Yield Volatilities What to Do with This Expression for the Convexity 	351 351 355 357 360 362 363
	The V 20.1 20.2 20.3 20.4	 Value of Convexity The Purpose of This Chapter Break-Even Volatility – The Vasicek Setting Problems with the Vasicek Version of the Break-Even Volatility Generalizing to Many Factors 20.4.1 Calculating the Terms c i, c i, c i, c i, c 20.4.2 Expressing the Convexity in Terms of Yield Volatilities What to Do with This Expression for the Convexity 20.5.1 An Important Aside 	351 351 355 357 360 362 363 364

21	A Mo	odel-Independent Approach to Valuing Convexity	371
	21.1	The Purpose of This Chapter	371
	21.2	Equivalent Affine Models	373
	21.3	The Expression for Convexity in an Affine Setting	374
	21.4	An Expression for the Theoretical Convexity of the	
		Portfolio	377
	21.5	Theoretical Convexity as a Function of Market Observables	380
		21.5.1 Theoretical Portfolio Convexity as a Function of	
		Forward Rates	380

23.6

23.7

23.8

24.1

Returns

Excess Returns with Real Rates

The Purpose of This Chapter

Why 'Carry' and 'Roll-Down' Matter

24 Risk Premia, the Market Price of Risk and Expected Excess

Market Lore

		21.5.2 The Portfolio Time Decay as a Function of 'Carry'	
		and 'Roll-Down'	381
	21.6	What These Results Imply	383
	21.7	Linking the Term $\frac{1}{2}$ Tr[S ^T DS] with Yield Volatilities	384
	21.8	Making the Weights (Almost) Model Independent	386
	21.9	How General Are the Results?	388
	21.10	Model-Based or Empirical?	389
22	Conve	exity: Empirical Results	391
	22.1	The Purpose of This Chapter	391
	22.2	The Strategy: A Reminder	393
	22.3	Setting Up the Strategy	395
		22.3.1 Determining the Optimal Weights	395
		22.3.2 Estimating the Yield Volatilities	396
	22.4	Results	398
		22.4.1 Is the Yield Curve Fairly Curved?	398
		22.4.2 Why Are the Strategies Not Always Profitable?	402
		22.4.3 Is the Strength of the Signal Correlated with the	
		Money Made?	405
		22.4.4 Explaining the Residuals – Residual Exposure?	406
		22.4.5 Explaining the Residuals – Wrong	
		Volatility Estimate?	409
	22.5	Conclusions	411
_			
Par	t VI E	xcess Returns	
23	Exces	s Returns: Setting the Scene	415
	23.1	The Purpose of This Chapter	415
	23.2	The (Local) Expectation Hypothesis	415
	23.3	What One Really Tests for When One Tests the (L)EH	417
	23.4	Defining Excess Returns	419
		23.4.1 General Exact Results	419
		23.4.2 Special Cases	420
		23.4.3 Approximate Results for the $\tau = n = 1$ Case	421
	23.5	Expressing Excess Returns as a Function of Forward Rates	422

Excess Returns: Links with Carry, Roll-Down and Related

422

425

429

431

431

	24.2	Decomposing and Interpreting the Approximate Excess	
		Returns	432
		24.2.1 The 'Carry' Description	432
		24.2.2 The 'Forwards-Come-True' Condition	432
	24.3	From Excess Returns to the Market Price of Risk	433
		24.3.1 Market Yields versus Expected Yields	433
	24.4	The Link between Excess Returns and Term Premia	436
	24.5	The Link between Term Premia and Expected Excess	
		Returns	438
	24.6	Reconciling Results	440
	24.7	Expected versus Realized Excess Returns	441
	24.8	Forwards-Come-True versus Yields-Don't-Move:	
		Roll-Down Again	446
	24.9	When to Invest	448
25	Excess Returns: Empirical Results		
	25.1	The Purpose of This Chapter	449
	25.2	Understanding the Empirical Setting	450
		25.2.1 The Empirical Questions	450
		25.2.2 A Very Important Caveat on Spanning	452
		25.2.3 The Methodological Dilemma	454
	25.3	Unconditional Results: Nominal Bonds	455
	25.4	Regression Results: Nominal Bonds	457
		25.4.1 1- to 10-Year Returns	457
		25.4.2 Effectiveness of Various Regressors	459
		25.4.3 5-Year Returns: Comparison with	
		Cochrane-Piazzesi (2005)	461
	25.5	Where Has the Volatility Gone?	462
	25.6	Regression Results: Real Bonds	
	25.7	The Data	
	25.8	The Real Excess Returns	464
	25.9	Extracting the Real-Rate Risk Premium	
	25.10	Estimating the Inflation Premium in Nominal Bonds	470
		25.10.1 Isolating the Liquidity Component	471
26	Excess Returns: The Recent Literature – I		
	26.1	The Purpose of This Chapter	
	26.2	The Early Work	
	26.3	Cochrane and Piazzesi (2005)	
	26.4	Critical Assessment of the Cochrane–Piazzesi	
		Results	478
	26.5	Robustness of the Tent Shape: Tents versus Bats	478

	26.6	The Li	nk Between the Tent and the Bat Factors:	
		Constr	ained Regressions	482
		26.6.1	Constrained Regression: The	
			Investigation Methodology	483
		26.6.2	Constrained Regression: Results	485
		26.6.3	Constrained Regression: First Conclusions	487
	26.7	The Li	nk between the Tent and the Slope Factors	488
		26.7.1	Tent versus Slope Shape Similarity: The	
			Investigation Methodology	488
		26.7.2	Tent versus Slope Shape Similarity: Results	490
	26.8	Explor	ing the Economic Robustness of Tent versus Slope	
		Predict	ions	491
		26.8.1	Tent versus Slope Robustness: Methodology	491
		26.8.2	Tent versus Slope Robustness: Results	493
		26.8.3	Tent versus Slope Robustness: Conclusions	495
27	Excess Returns: The Recent Literature – II			
	27.1	The Pu	rpose of This Chapter	497
	27.2	The We	ork of Radwanski (2010)	498
		27.2.1	Features and Highlights of the Radwanski Results	498
		27.2.2	The Methodology and Results	499
		27.2.3	Comments and Conclusions	503
	27.3	The Wo	ork of Ludvigson and Ng (2009)	504
		27.3.1	Main Results	504
		27.3.2	The Spanning of Yield Curve Factors Revisited:	
			Implication for Affine Models	507
	27.4	4.4 Yield-Curve Spanning: Why One May Need Five Factors		
		After A	M	508
		27.4.1	The Essentially Affine Description	509
		27.4.2	Switching to Yields as State Variables	511
		27.4.3	Augmenting the State Vector	511
		27.4.4	Switching Back to an 'Augmented' Set of Yields as	
			State Variables	512
		27.4.5	The Subtle Role of 'Measurement Error'	513
		27.4.6	Spanning in Principle versus Spanning in Practice	513
	27.5	The Wo	ork of Cieslak and Povala	514
		27.5.1	The Set-Up and Main Features	514
		27.5.2	The Investigation Methodology and Results	515
		27.5.3	The Link with Forward-Rate-Based RPFs	519
		27.5.4	Intrinsic Limitations of Forward-Rate-Based	
			Factors	520
		27.5.5	Implications for Term-Structure Models	522

		27.5.6 Re-Interpretation of the Cieslak–Povala RPF:	
		Conditional Slope and Level	522
	27.6	Related Work	525
28	Why Is the Slope a Good Predictor?		
	28.1	The Purpose of This Chapter	527
	28.2	What Does Not Qualify as an Explanation	528
	28.3	Excess Returns, the Slope and the Real Economy	529
	28.4	The Data-Generating, Subjective and Risk-Neutral	
		Measures	531
	28.5	Does It Matter?	533
	28.6	Why Is the Slope Significant? A	
		Heterogeneous-Expectations Model	534
	28.7	Why Is the Slope Significant? An Over-reaction Model	538
	28.8	The Model in Detail	539
		28.8.1 The Actions of the Central Bank	539
		28.8.2 The Investors' Expectations	541
		28.8.3 The Bond Price Formation	541
		28.8.4 The Excess Returns	542
		28.8.5 The Simulations	542
		28.8.6 Summary of Results	546
29	The Spanning Problem Revisited		
	29.1	The Purpose of This Chapter	547
	29.2	What Is the Spanning Problem?	547
	29.3	The Empirical Spanning Problem	548
	29.4	The Theoretical Spanning Problem	551
	29.5	The Modelling Choices to Handle the Spanning Problem	552
Par	t VII	What the Models Tell Us	
30	The I	Doubly Mean-Reverting Vasicek Model	559
	30.1	The Purpose of This Chapter	559
	30.2	The Doubly Mean-Reverting Vasicek Model	560
	30.3	Bond Prices and Properties of the Solution	561
	30.4	The Volatility of the Instantaneous Forward Rate	562
	30.5	The Building Blocks	564
	30.6	Initial Conclusions	568
	30.7	Quality of the Fit	569
		30.7.1 Calibrating the Model to the Volatility Structure	569
		30.7.2 Calibrating the Model to the Yield Curve	571
	30.8	The Value of Convexity	573
	30.9	What Happened to the \mathbb{P} -Measure?	574

31	Real	Yields, Nominal Yields and Inflation: The		
-	D'An	nico–Kim–Wei Model	575	
	31.1	The Purpose of This Chapter	575	
	31.2	Empirical Findings about Inflation	576	
	31.3	The No-Arbitrage Relationships	577	
		31.3.1 What the No-Arbitrage Relationships Really Imply	579	
	31.4	The Assumptions About the Process for the State Variables	581	
	31.5	Inflation Expectations and Risk Premia	582	
	31.6	Adding Liquidity	583	
	31.7	The Parameter Estimation Procedure and Results	584	
		31.7.1 The Difficulty of Parameter Estimation	586	
	31.8	Nominal and Real Rate Expectations and Risk Premia	588	
		31.8.1 Full-Sample Analysis	588	
		31.8.2 Prediction of Nominal and Real Excess Returns	589	
		31.8.3 Analysis of the May–September 2013 Events	594	
	31.9	Conclusions	596	
	31.10	Related Work	599	
32	From Snapshots to Structural Models: The Diebold–Rudebusch			
52	Approach		602	
	32.1	The Purpose of This Chapter	602	
	32.2	Turning a Snapshot Model into a Dynamic Model	603	
	32.3	Turning a Dynamic Model into a No-Arbitrage Affine	000	
		Model	606	
	32.4	Are the Variables Really Principal Components?	610	
	32.5	Dealing with Liquidity	612	
		32.5.1 On-the-Run, Off-the-Run Bonds	612	
		32.5.2 The Modelling Approach	613	
		32.5.3 The Results	615	
		32.5.4 Conclusions	616	
~~	.			
33		pal Components as State Variables of Affine Models: The	(10)	
		Affine Approach	618	
	33.1	The Purpose of This Chapter	618	
	33.2	Why PC-Based Models Are Special (Again)	620	
	33.3	Specified-Variable Models Revisited	622	
	22.4	33.3.1 Parameter Constraints for PCA Prespecified Models	624	
	33.4	Our Strategy to Link the \mathbb{P} - and \mathbb{Q} -Measures	625	
	33.5	The Set-Up	626	
		33.5.1 Notation	626	
		33.5.2 The Geometry (Kinematics) of the Problem	626	
		33.5.3 The Dynamics of the Problem	627	

		33.5.4 Solution	628
		33.5.5 Necessary Conditions for Identifiability	629
	33.6	Theoretical Results	631
		33.6.1 Impossibility of Identification When \mathcal{K} Is	
		Diagonal	631
		33.6.2 What Does It Mean to Require that the Factors \vec{x}_{t}	
		Should Be Principal Components?	632
		33.6.3 Constraints on \mathcal{K} for Identifiability	633
		33.6.4 What the \mathbb{Q} -measure Reversion-Speed Matrix	
		Affects	635
	33.7	Moving from the \mathbb{Q} - to the \mathbb{P} -Measure	639
	33.8	Estimating the Parameters of \overrightarrow{q}_0 and $\underline{\mathcal{R}}$	641
	33.9	Calibration of the Model	643
		33.9.1 Cross-Sectional Fit to Yields	643
		33.9.2 Estimating the Values of the Eigenvalues \vec{l}	644
		33.9.3 Estimating the 'Level' Constant, u_r	644
	33.10	Calibration Results	644
	33.11	Generalizable Results on Term Premia from a PC-Based	
		Affine Model	649
	33.12	The Existential Dilemma	654
	33.13	Appendix 33A: Proof of the Constraints on the	
		Reversion-Speed Matrix $\mathcal{K}^{\mathbb{Q}}$	657
		33.13.1 Preliminaries	657
		33.13.2 Some Ancillary Results	658
		33.13.3 The Derivation of the Main Result	659
		33.13.4 The Conditions on the Vector \vec{e}	660
	33.14	Appendix 33B: Switching Regressors	661
34	Generalizations: The Adrian–Crump–Moench Model		
	34.1	The Purpose of This Chapter	663
	34.2	The Strategy Behind the Adrian–Crump–Moench Model	664
	34.3	A High-Level Description of the Model	665
	34.4	State-Price Deflators: Generalizing the Results	667
	34.5	Establishing an Expression for the Excess Returns	671
	34.6	The Estimation Procedure	676
	34.7	Establishing a Link with the Affine Model: The Discount	
		Factor	677
	34.8	Some Observations	679
	34.9	Results	680
		34.9.1 Full-Sample Analysis	680
		34.9.2 Analysis of the May–September 2013 Events	683
	34.10	Conclusions	687

35	An A	ffine, Stochastic-Market-Price-of-Risk Model	688		
	35.1	The Purpose of This Chapter	688		
	35.2	Why Do We Need Another Affine Model?	689		
	35.3	Another Justification for a Stochastic-Market-Price-of-Risk			
		Model	691		
	35.4	The Model	693		
	35.5	In Which Measure(s) Are We Working?	694		
	35.6	The Qualitative Behaviour of the Model	696		
	35.7	Calibration of the Model	698		
	35.8	Calibration Results	700		
	35.9	Comments on the Solution	705		
	35.10	Term Premia in the Stochastic-Market-Price-of-Risk Model	708		
36	Concl	onclusions			
	36.1	What Have We Learnt?	714		
		36.1.1 The Road Followed	714		
		36.1.2 The Case for the Prosecution: Models			
		As Regurgitators	715		
		36.1.3 The Case for the Defence: Models as Enforcers of			
		Parsimony	716		
		36.1.4 The Case for the Defence: Models as Enforcers of			
		Cross-Sectional Restrictions	718		
		36.1.5 The Case for the Defence: Models as Revealers of			
		Forward-Looking Informations	719		
		36.1.6 The Case for the Defence: Models as Integrators	720		
		36.1.7 The Case for the Defence: Models as Enhancers of			
		Understanding	721		
Ref	erences		725		
Inde	ex		737		