Fields Institute Monographs

VOLUME 29

The Fields Institute for Research in Mathematical Sciences

Fields Institute Editorial Board:

Carl R. Riehm, Managing Editor

Edward Bierstone, Director of the Institute

Matheus Grasselli, Deputy Director of the Institute

James G. Arthur, University of Toronto

Kenneth R. Davidson, University of Waterloo

Lisa Jeffrey, University of Toronto

Barbara Lee Keyfitz, Ohio State University

Thomas S. Salisbury, York University

Noriko Yui, Queen's University

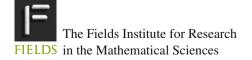
The Fields Institute is a centre for research in the mathematical sciences, located in Toronto, Canada. The Institutes mission is to advance global mathematical activity in the areas of research, education and innovation. The Fields Institute is supported by the Ontario Ministry of Training, Colleges and Universities, the Natural Sciences and Engineering Research Council of Canada, and seven Principal Sponsoring Universities in Ontario (Carleton, McMaster, Ottawa, Toronto, Waterloo, Western and York), as well as by a growing list of Affiliate Universities in Canada, the U.S. and Europe, and several commercial and industrial partners.

For further volumes: http://www.springer.com/series/10502

Nizar Touzi

Optimal Stochastic Control, Stochastic Target Problems, and Backward SDE

With Chapter 13 by Agnès Tourin





Nizar Touzi Département de Mathématiques Appliquées École Polytechnique Palaiseau Cedex France

ISSN 1069-5273 ISSN 2194-3079 (electronic)
ISBN 978-1-4614-4285-1 ISBN 978-1-4614-4286-8 (eBook)
DOI 10.1007/978-1-4614-4286-8
Springer New York Heidelberg Dordrecht London

Library of Congress Control Number: 2012943958

Mathematics Subject Classification (2010): 03C64, 14P15, 26A12, 26A93, 32C05, 32S65, 34C08, 34M40, 37S75, 58A17

© Springer Science+Business Media New York 2013

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed. Exempted from this legal reservation are brief excerpts in connection with reviews or scholarly analysis or material supplied specifically for the purpose of being entered and executed on a computer system, for exclusive use by the purchaser of the work. Duplication of this publication or parts thereof is permitted only under the provisions of the Copyright Law of the Publisher's location, in its current version, and permission for use must always be obtained from Springer. Permissions for use may be obtained through RightsLink at the Copyright Clearance Center. Violations are liable to prosecution under the respective Copyright Law.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

While the advice and information in this book are believed to be true and accurate at the date of publication, neither the authors nor the editors nor the publisher can accept any legal responsibility for any errors or omissions that may be made. The publisher makes no warranty, express or implied, with respect to the material contained herein.

Cover illustration: Drawing of J.C. Fields by Keith Yeomans

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

I should like to express all my love to my family: Christine, our sons Ali and Héni, and our daughter Lilia, who accompanied me during this visit to Toronto, all my thanks to them for their patience while I was preparing these notes,

and all my apologies for my absence even when I was physically present...

Contents

I	ntro	duction		
(Cond	ditional 1	Expectation and Linear Parabolic PDEs	
2	2.1	Stocha	stic Differential Equations	
2	2.2	Markovian Solutions of SDEs		
2	2.3	Conne	ction with Linear Partial Differential Equations	
		2.3.1	Generator	
		2.3.2	Cauchy Problem and the Feynman–Kac	
			Representation	
		2.3.3	Representation of the Dirichlet Problem	
2	2.4	The Bl	lack–Scholes Model	
		2.4.1	The Continuous-Time Financial Market	
		2.4.2	Portfolio and Wealth Process	
		2.4.3	Admissible Portfolios and No-Arbitrage	
		2.4.4	Super-Hedging and No-Arbitrage Bounds	
		2.4.5	The No-Arbitrage Valuation Formula	
		2.4.6	PDE Characterization of the Black–Scholes Price	
S	Stochastic Control and Dynamic Programming			
3	3.1	Stochastic Control Problems in Standard Form		
3	3.2	The Dynamic Programming Principle		
		3.2.1	A Weak Dynamic Programming Principle	
		3.2.2	Dynamic Programming Without Measurable Selection	
3	3.3	The D	ynamic Programming Equation	
3	3.4	On the	Regularity of the Value Function	
		3.4.1	Continuity of the Value Function for Bounded	
			Controls	
		3.4.2	A Deterministic Control Problem with Non-smooth	
			Value Function	
		3.4.3	A Stochastic Control Problem with Non-smooth	
			Value Function	

viii Contents

4	Opti 4.1	imal Stopping and Dynamic Programming Optimal Stopping Problems	39 39		
	4.2	The Dynamic Programming Principle	41		
	4.3	The Dynamic Programming Equation	43		
	4.4	Regularity of the Value Function	45		
	4.4		45		
			43		
		Tr S	4/		
		4.4.3 An Optimal Stopping Problem with Nonsmooth	50		
		Value	50		
5		ing Control Problems by Verification	53		
	5.1	The Verification Argument for Stochastic Control Problems	53		
	5.2	Examples of Control Problems with Explicit Solutions	57		
		5.2.1 Optimal Portfolio Allocation	57		
		5.2.2 Law of Iterated Logarithm for Double			
		Stochastic Integrals	58		
	5.3	The Verification Argument for Optimal Stopping Problems	62		
	5.4	Examples of Optimal Stopping Problems with Explicit			
		Solutions	64		
		5.4.1 Perpetual American Options	64		
		5.4.2 Finite Horizon American Options	66		
6	Introduction to Viscosity Solutions				
	6.1	Intuition Behind Viscosity Solutions			
	6.2	Definition of Viscosity Solutions			
	6.3	First Properties			
	6.4	Comparison Result and Uniqueness			
		6.4.1 Comparison of Classical Solutions in a Bounded			
		Domain	73		
		6.4.2 Semijets Definition of Viscosity Solutions	74		
		6.4.3 The Crandall–Ishii's Lemma	75		
		6.4.4 Comparison of Viscosity Solutions in a Bounded			
		Domain	76		
	6.5	Comparison in Unbounded Domains	80		
	6.6	Useful Applications	83		
	6.7	Proof of the Crandall–Ishii's Lemma	84		
7	Dyna	amic Programming Equation in the Viscosity Sense	89		
	7.1	DPE for Stochastic Control Problems	89		
	7.2	DPE for Optimal Stopping Problems	95		
	7.3	A Comparison Result for Obstacle Problems	98		
8	Stoc	hastic Target Problems	101		
	8.1	Stochastic Target Problems	101		
		•	101		
			102		

Contents ix

		8.1.3	The Dynamic Programming Equation	104	
		8.1.4	Application: Hedging Under Portfolio Constraints	110	
	8.2		stic Target Problem with Controlled Probability		
			ress	112	
		8.2.1	Reduction to a Stochastic Target Problem	113	
		8.2.2	The Dynamic Programming Equation	114	
		8.2.3	Application: Quantile Hedging in the Black–Scholes	115	
			Model	115	
9	Secon	nd Orde	r Stochastic Target Problems	123	
	9.1	Superh	edging Under Gamma Constraints	123	
		9.1.1	Problem Formulation	124	
		9.1.2	Hedging Under Upper Gamma Constraint	126	
		9.1.3	Including the Lower Bound on the Gamma	132	
	9.2		Order Target Problem	134	
		9.2.1	Problem Formulation	134	
		9.2.2	The Geometric Dynamic Programming	136	
		9.2.3	The Dynamic Programming Equation	137	
	9.3	Superh	edging Under Illiquidity Cost	145	
10	Back	Backward SDEs and Stochastic Control			
	10.1		tion and Examples	149	
		10.1.1	The Stochastic Pontryagin Maximum Principle	150	
		10.1.2	BSDEs and Stochastic Target Problems	152	
		10.1.3	BSDEs and Finance	153	
	10.2	Wellpo	sedness of BSDEs	154	
		10.2.1	Martingale Representation for Zero Generator	154	
		10.2.2	BSDEs with Affine Generator	155	
		10.2.3	The Main Existence and Uniqueness Result	156 159	
	10.3	Comparison and Stability			
	10.4		and Stochastic Control	160	
	10.5		and Semilinear PDEs	162	
	10.6	Append	dix: Essential Supremum	164	
11	Onac	Iratic Ba	ickward SDEs	165	
	11.1		i Estimates and Uniqueness	166	
		11.1.1	A Priori Estimates for Bounded <i>Y</i>	166	
		11.1.2	Some Properties of BMO Martingales	167	
		11.1.3	Uniqueness	168	
	11.2		ice	169	
		11.2.1	Existence for Small Final Condition	169	
		11.2.2	Existence for Bounded Final Condition	172	
	11.3	Portfoli	io Optimization Under Constraints	175	
		11.3.1	Problem Formulation	175	
			BSDE Characterization	177	

x Contents

	11.4	.4 Interacting Investors with Performance Concern		
		11.4.1	The Nash Equilibrium Problem	181
		11.4.2	The Individual Optimization Problem	182
		11.4.3	The Case of Linear Constraints	183
		11.4.4	Nash Equilibrium Under Deterministic Coefficients	186
12	Prob	abilistic l	Numerical Methods for Nonlinear PDEs	189
	12.1	Discreti	zation	190
	12.2	Converg	gence of the Discrete-Time Approximation	193
	12.3	Consist	ency, Monotonicity and Stability	195
	12.4	The Bar	rles-Souganidis Monotone Scheme	197
13	Intro	duction 1	to Finite Differences Methods	201
	13.1	Overvie	ew of the Barles–Souganidis Framework	201
	13.2	First Ex	amples	203
		13.2.1	The Heat Equation: The Classic Explicit	
			and Implicit Schemes	203
		13.2.2	The Black–Scholes–Merton PDE	206
	13.3	A Nonli	inear Example: The Passport Option	206
		13.3.1	Problem Formulation	206
		13.3.2	Finite Difference Approximation	207
		13.3.3	Howard Algorithm	209
	13.4	The Bo	nnans–Zidani [7] Approximation	209
	13.5			211
	13.6	Variatio	onal Inequalities and Splitting Methods	211
		13.6.1	The American Option	211
Dof	orongo	e.		213
17CI	CI CIICE	3		413