## **Dynamic Optimization**

The Calculus of Variations and Optimal Control in Economics and Management

Series Volume 4

## Morton I. Kamien

and Nancy L. Schwartz

Northwestern University



NORTH HOLLAND New York • Oxford



## Contents

Preface			ix
		PART I. CALCULUS OF VARIATIONS	1
Section	1.	Introduction production, growth, investment	3
Section	2.	Example Solved	11
Section	3.	Simplest Problem—Euler Equation	14
Section	4.	Examples and Interpretations production, consumption	20
Section	5.	Solving the Euler Equation in Special Cases production, investment, pricing, exhaustible resource	28
Section	6.	Second Order Conditions	37
Section	7.	Isoperimetric Problem exhaustible resource	43
Section	8.	Free End Value checking systems that may fail	48
Section	9.	Free Horizon—Transversality Conditions production, consumption, exhaustible resource	53
Section	10.	Equality Constrained Endpoint minority neighborhood	61

Contents

Section	11.	Salvage Value research and development	66
Section	12.	Inequality Constrained Endpoint land use	72
Section	13.	Corners	79
Section	14.	Inequality Constraints in $(t, x)$ production	83
Section	15.	Infinite Horizon Autonomous Problems	88
Section	16.	Most Rapid Approach Paths advertising, investment, fishing	90
Section	17.	Diagrammatic Analysis growth	95
Section	18.	Several Functions	104
		PART II. OPTIMAL CONTROL	109
Section	1.	Introduction production planning, growth, investment	111
Section	2.	Simplest Problem—Necessary Conditions new product pricing	114
Section	3.	Sufficiency	122
Section	4.	Interpretations investment	125
Section	5.	Several Variables	130
Section	6.	Fixed Endpoint Problems production, growth with an exhaustible resource	135
Section	7.	Various Endpoint Conditions consumption	143
Section	8.	Discounting, Current Values, Comparative Dynamics investment, pollution	151
Section	9.	Equilibria in Infinite Horizon Autonomous Problems advertising, growth, fishing	159

Contents

Section 10.	Bounded Controls production, machine maintenance and sale, human capital	170
Section 11.	Further Control Constraint	180
Section 12.	Discontinuous and Bang-Bang Control investment, machine maintenance	186
Section 13.	Singular Solutions and Most Rapid Approach Paths road building, investment, advertising, growth	193
Section 14.	The Pontryagin Maximum Principle, Existence	201
Section 15.	Further Sufficiency Theorems growth, limit pricing	204
Section 16.	Alternative Formulations	212
Section 17.	State Variable Inequality Constraints pollution, dividends	215
Section 18.	Jumps in the State Variable product diversity	226
Section 19.	Delayed Response limit pricing, investment	233
Section 20.	Dynamic Programming	238
Section 21.	Stochastic Optimal Control consumption and investment in risky and riskless assets	243
	APPENDIX A. CALCULUS AND NONLINEAR PROGRAMMING	251
Section 1.	Calculus Techniques	253
Section 2.	Mean-Value Theorems	256
Section 3.	Concave and Convex Functions	260
Section 4.	Maxima and Minima	265
Section 5.	Equality Constrained Optimization	269
Section 6.	Inequality Constrained Optimization	275
Section 7.	Line Integrals and Green's Theorem	282

vii

APPENDIX B. DIFFERENTIAL EQUATIONS	285
1. Introduction	287
2. Linear First Order Differential Equations	290
3. Linear Second Order Differential Equations	294
4. Linear nth Order Differential Equations	301
5. A Pair of Linear Equations	306
6. Existence and Uniqueness of Solutions	312
References	
Author Index	
Subject Index	
	<ol> <li>Introduction</li> <li>Linear First Order Differential Equations</li> <li>Linear Second Order Differential Equations</li> <li>Linear nth Order Differential Equations</li> <li>A Pair of Linear Equations</li> <li>Existence and Uniqueness of Solutions</li> </ol>