TECHNOLOGY, GROWTH, AND DEVELOPMENT

An Induced Innovation Perspective

Vernon W. Ruttan

New York Oxford
OXFORD UNIVERSITY PRESS
2001

Contents

Preface xv

PART ONE © PRODUCTIVITY AND ECONOMIC GROWTH ^

1 Is Economic Growth Sustainable? 3

Doomsters and Boomsters 3
The Dismal Science 4
Limits to Growth 6
Productivity Growth S 1 '
The Book Plan 13
References 13

2 Catching Up and Falling Behind 15

The Convergence Controversy 15
A Convergence Club? 17
The Deck Was Stacked 19
Conditional Convergence 20
Growth Economics 23
Keynesian Growth 23
Neoclassical Growth 24
Endogenous Growth 25
Accounting for Economic Growth 29
Comparative Productivity Growth 30
Productivity Trends in the United States 32
Falling Behind 36
Energy and Raw Material Prices 37
Capital Formation 37
Public Infrastructure Investment 38
The Service Sector 38
Technical Change 39
Failure to Measure 39
Perspective 42
References 44
Appendix: Technical Change and Productivity Growth: Some Simple Analytics 47
Index Numbers and Production Functions 47

Measuring Technical Change: The Index Number Approach 48
Measuring Technical Change: The Production Function Approach 49
Definition of Inputs and Outputs 51
Sources of Bias in Productivity Measurement 52
Changes in Factor and Product Prices 52
Bias due to Nonneutrality 54
Bias due to Changes in Relative Prices and Changes in Neutrality 56
Disequilibrium in Factor and Product Markets 58
Scale, Size, and Scope 58
References 60

PART TWO © SOURCES OF TECHNICAL CHANCE 6I

3 The Process of Invention and Innovation 63

Invention and Innovation 64
Schumpeterian Innovation 64
Sources of Invention 65
Cumulative Synthesis: Three Cases 70
The Watt-Boulton Steam Engine 70
Modern Varieties of Rice 74
The Microprocessor 78
Linkages between Science and Technology 79
The Research Institution 82
Research Output 85
Intermediate Processes 88
Learning by Doing and Using 89
Liberty Ships 91
Semiconductors 92
Perspective 95
References 95

4 Technical and Institutional Innovation TOO

Sources of Technical Change 100
Induced Technical Change 101
Evolutionary Theory 109
Path Dependence 112
Toward a More General Theory? 116
Sources of Institutional Innovation ~\ 18
What Is Institutional Innovation? 119
Demand for Institutional Innovation: Property Rights and Market Institutions 121

The Demand for Institutional Innovation-Nonmarket Institutions for the Supply of Public Goods 127
The Supply of Institutional Innovation 130
Social Science Knowledge 132
A Pattern Model of Induced Innovation 133
References 137

5 Technology Adoption, Diffusion, and Transfer 147

Convergence of Tradition s 148
The Diffusion of Agricultural Technology 149
Diffusion of Industrial Technology 153
Diffusion of the Diesel Locomotive 154
The Basic Oxygen Steel (Ease 156
New Theory and New Method 160
Equilibrium Models 160
Evolutionary Models 162
The Product Cycle and International Trade 163
Endogenous Growth ahd Technology Transfer 166
The Costs of Technology Transfer 167
Resistance to Technology 170
Perspective 171
References 172

PARTTHREE O TECHNICAL INNOVATION AND INDUSTRIAL CHANGE 177

6 Technical Change and Agricultural Development 179

Models of Agricultural Development 180
The Resource Exploitation Model 180
The Conservation Model 182
The Diffusion Model 183
The High-Payoff Input Model 186
Induced Technical Change in Agriculture 188
Mechanical Processes 188
Biological and Chemical Processes 190
The Metaproduction Function 192
Scientific and Technical Constraints 196
Resource and Environmental Constraints 199
Soil 200

Water 201
Pest Control 203
Health 205
Climate Change 206
Agricultural Research Systems 207
The U.S. System 209
The International Agricultural Research System 214
Strengthening National Research Systems 218
An Incomplete System 223
Lessons from Experience 224
References 225

7 Light, Power, and Energy 235

The Battle of the Systems 236
Edison's Direct Current System 237
The Alternating Current Challenge 240
Conflict 242
Resolution 243
Institutional Innovation 245
The Transformation of Industrial Energy Use 247
Electrification of Mechanical Drive 247
The Steam Turbine 250
Electric Power and Productivity Growth 253
The Great Oil Shock 253
Output and Employment 257
Grqwth and Productivity 258
The Exhaustion of Scale 260
The Technology of Electricity Generation 261
What Happened to Nuclear Power 262
A Faustian Bargain? 265
Institutional Innovation 266
Clean Air Policy 267
Renewable Energy Policy 268
Deregulation 269
What Happened to Alternative Energy? 270
Energy Conservation 271
Renewable Energy Sources 274
Small Is Beautiful 278
Perspective 279
References 281

8 Technical Change in the Chemical Industry 286

Inventors, Inventions, and Technical Change 287
Synthetic Dyestuffs 287
The Haber-Bosch Process 290
The Invention of Nylon 291
Chemical Engineering and the Petrochemical Revolution 294
Chemical Engineering 294
Petrochemicals 297
International Diffusion 300
Western Europe 301
lapan and U.S.S.R. 302
Developing Countries 304
Toward Maturity 308 1 '
Perspective 312
References 313

9 The Computer and Semiconductor Industries 316

From Calculators to Computers 317
Tabulators and Calculators 317
Electronic Digital Computers 319
Commercial Development 320
IBM Sets the Mainframe Standard 322
The Transistor Revolution 323
The Point-Contact Transistor 324
Integrated Circuits 325
The Microprocessor 325
Diffusion of Semiconductor Production 328
Minicomputers and Microcomputers 331
Apple in the Lead 332
IBM Forges Ahead 333
Apple Falls 334
The Silverlake Project 335
The Software Industry 338
International Diffusion 343
Computers 344
Semiconductors 347
The Landscape Shifts 349
The Late-Late Developers 350
Industrial Policy 353
Falling Behind 353

Semiconductor Trade Accords 354
Sematech 356
Computers and Economic Growth 357
Computers and Society 362
References 363

10 The Biotechnology Industries 368

From Biological Technology to Biotechnology 369
Genetics and Plant Breeding 370
Fermentation and Pharmaceuticals 372
Molecular Biology and Biotechnology 373
Concern about DNA 374
The University-Industrial Complex 377
Science Entrepreneurs 377
Industrial Organization 379
Institutional Innovation 384
Regulatory Regimes 385
Patenting Life 385
Commercial Biotechnology 389
The Pharmaceutical Industry 389
Agricultural Biotechnology 394
Economic Impacts of Agricultural Biotechnology 399
Market Structure 401
The Biotechnology Challenge 402
Restructuring 403
Industrial Policy and International Competition 405
A lapanese Challenge? 406
Developing Countries 408
Biotechnology and the Food Industries 411
Biotechnology in the Twenty-First Century 412
References 414
Appendix: Terms Used in Molecular Biology and Biotechnology 418

PART FOUR % TECHNOLOGY POLICY 423

n TechnicalInnovation in Three Systems 425 '

American Systems of Technical Innovation 426
Interchangeable Parts 426
Mass Production 428

Science-Based Technology 436
The lapanese System 440
Cotton Textiles 441
lapan as Number One 443
The Automobile Industry *\^\
Science-Based Technology 452
Perspective 454
German Systems of Technical Innovation 456
Science-Based Technology 457
Fordism and Beyond 460
Toward Revival 462
Systems of Technical Innovation 463
Technology, Trade, and Competitiveness 468
Perspective 471
References 473

12 Technology, Resources, and Environment 478

Three Waves of Concern 479
Resource Requirements for Growth 479
Demand for Environmental Services 479
Global Change 480
Resource Economics 480
Nonrenewable Resources 481
Renewable Resources 485
Environmental Economics 487
Externalities 489
Valuation 490
Ecological Economics 492
Environmental Impacts of Production 494
Material Flows 494
Impact of Material Flows 500
Environmental Impacts of Consumption 505
Emissions Trading 511
Global Climate Change 515
Human Forcing 516
Impact 517
Institutional Design 520
Perspective 522
References 522

13 Science and Technology Policy 534

Principles of Science and Technology Policy 535
Doing Science and Doing Technology 535
The Underinvestment Rationale 538
The Patent System 542
Controversy about Patents 543
New Perspectives 545
Military Procurement 547
Spin-off, Spin-away, and Spin-on 547
The Defense-Industrial Base 551
Politics of Science and Technology Policy 552
Stages in Research and Development Policy 554
Science in the White House 557
Science Advice to the Congress 560
Advice from Nongovernmental Organizations 561
Issues in Science and Technology Policy 563
Policy Objectives 563
Measuring and Evaluating 567
Transforming the Technology Base 570
Big Science 571
Commercial Technology 575
An Implicit Social Contract 583
Experience with Public Investment 585
Procurement-Related Technology 586
Decentralized Generic Technology 586
Client-Oriented Technology 586
Picking Winners 587
Perspective 588
References 590

14 The Transition to Sustainable Development 600

What Have We Learned? 600
General Purpose Technologies 600
Induced Innovation 601
Government Role 602
Mature Industries 602
Bending the Trajectory 603
The Sustainability Critique 604
Modeling the Future 607
Conventional Worlds 608
Great Transformations 609

Barbarization 61 o
Sustainability Transitions 6n
Food 613
Health 614
Environment 615
Intellectual Challenges 616
Substitutability 617
Obligations Toward the Future 617
Institutional Design 618
Perspective 619
References 620

Author Index 624
Subject Index 636