## Contents

**List of Figures**

**Preface**

1. **ONTOLOGY**

1.1 The naturalistic turn in economics and the physical nature of knowledge
   1.1.1 The changing nature of economics
   1.1.2 The meaning of ‘naturalism’
   1.1.3 Natural Philosophy: Hegel and Peirce
   1.1.4 The Aristotelian notion of causal explanation
   1.1.5 The Principle of Bimodality
   1.1.6 Externalism and naturalism in economics

1.2 Towards a principled theory of economics:
   1.2.1 Impossibility theorems on mind
   1.2.2 The Hayek impossibility theorem on brain and mind
   1.2.3 The gap between brain and mind
   1.2.4 Peircian triadism
   1.2.5 Minds are signs
   1.2.6 Naturalizing Wittgenstein’s ‘Private Language’ argument
   1.2.7 The externalist approach to brain and mind
   1.2.8 The two worlds
   1.2.9 Signs and existence

1.3 Observer relativity and the semiotic triad:
   1.3.1 Observer independent and observer relative facts
   1.3.2 The emergence of information
   1.3.3 Fisher information and dynamic epistemics
   1.3.4 The fundamental semiotic triad in knowledge generation
   1.3.5 Semiotic realism and the semioverse
   1.3.6 Physical information generation

1.4 Consilience and economic analysis
   1.4.1 Four approaches to reality
   1.4.2 Implications for economics as a science
   1.4.3 Consilience
2. CAUSATION

2.1 Thermodynamics and knowledge
   2.1.1 The conceptual framework of Thermodynamics 62
   2.1.2 Entropy and generation of information 66
   2.1.3 Entropy and observation 69

2.2 Randomness
   2.2.1 Entropy: The view from Natural Philosophy 72
   2.2.2 Randomness: Observer relative or observer independent? 74
   2.2.3 Lessons taught by Maxwell’s demon 76
   2.2.4 Propensities and probabilities 78
   2.2.5 ‘Individuals’ as a fundamental ontological category 81

2.3 Emergent information and the Second Law
   2.3.1 Regularities as kinds of constraints on change 84
   2.3.2 Evolution of knowledge as evolution of constraints 86
   2.3.3 Growth of knowledge as expression of the Second Law 88
   2.3.4 Irreversibility and causation 90
   2.3.5 The Second Law and finality 93
   2.3.6 Triadic causal modes, generation of information and irreversibility 97

2.4 Functions and Maximum Entropy Production
   2.4.1 Fundamental forms of functions 103
   2.4.2 Autocatalytic functions and hypercycles 105
   2.4.3 Lotka’s Maximum Power Principle 109
   2.4.4 Maximum Power and Maximum Entropy Production 112
   2.4.5 Maximum Entropy Production and the Constructal Law 115

2.5 Physiosemiosis and Gaia
   2.5.1 Kauffman’s ‘Fourth Law’ restated in triadic terms 118
   2.5.2 PIDs as self-referential heat engines 121
   2.5.3 A measure for evolving information in physiosemiosis 123
   2.5.4 Emergent hierarchies in physiosemiosis and ‘Gaia’ 126
   2.5.5 Maximum Entropy Production in the Earth System 129

3. EVOLUTION

3.1 Evolution, entropy and information
   3.1.1 The meanings of ‘evolution’ 135
   3.1.2 Dissipation of energy and origins of life 137
   3.1.3 Entropy and evolution: Fundamentals 139
   3.1.4 Evolution maximizes Fisher information 143

3.2 The theory of selection
   3.2.1 Price’s equation and heredity 147
   3.2.2 Fisher’s ‘Fundamental Theorem’ as an impossibility theorem 149
6.1.4 Institutions and technology 348

6.2 Institutional semiosis:
   Emergence of institutions from networks 351
   6.2.1 The substantive view on institutions 351
   6.2.2 Institutional semiosis 354
   6.2.3 Induction and the primordial emergence of institutions 358
   6.2.4 Metaphors and hypercyclic abstraction of regularities 362
   6.2.5 Emergence of abstract rules as institutions 364

6.3 Institutions and cognition 366
   6.3.1 Institutions and language 366
   6.3.2 Status functions as metaphors 369
   6.3.3 Cognitive path dependence of institutions 372
   6.3.4 An impossibility theorem on institutional evolution 376

6.4 Performativity of institutions 378
   6.4.1 Performing institutions 378
   6.4.2 Case study: The emergence of early money 382
   6.4.3 Performativity of money 387
   6.4.4 Evolutionary microfoundations of the theory of institutions 390

6.5 Culture, cognition and the diversity of institutions 393
   6.5.1 Functional equivalence of different kinds of institutions 393
   6.5.2 A simple taxonomy of institutions 397
   6.5.3 Culture and institutional diversity: China and Europe 402

6.6 The evolution of power and the emergence of institutions 405
   6.6.1 The ‘specialization dilemma’ 405
   6.6.2 Power projection and scope of institutions 408
   6.6.3 Agriculture and formal institutionalization 411
   6.6.4 The biology of institutions 415
   6.6.5 The general evolutionary model of institutions 419

7. TECHNOLOGY 424

7.1 Technology and human nature 424
   7.1.1 Human niche construction by means of technology 424
   7.1.2 Technological evolution, human intentionality and alienation 426
   7.1.3 The analytical irrelevance of ‘consumption’ 429
   7.1.4 Technology and multi–level evolution 432

7.2 Technology as embodied knowledge 434
   7.2.1 Artefacts and actors 434
   7.2.2 Kinds of knowledge, design and technological functions 436
   7.2.3 Technological semiosis 439
   7.2.4 Routines 443

7.3 Evolutionary trajectories of technological creativity 447
7.3.1 Artefacts as replicators in technological evolution 447
7.3.2 The problem of technological taxonomy 448
7.3.3 Branching out of technologies 451
7.3.4 Technological creativity 455
7.3.5 Standardization and the evolving state space of technology 459

7.4 Technology, production and energy 463
7.4.1 Consumption as production 463
7.4.2 Technology and entropy 466
7.4.3 Hypercyclic leveraging of energy throughputs by technological evolution 469
7.4.4 The transition to agriculture 471
7.4.5 The modern carbon–based economy 474
7.4.6 Technology, energy transformations and MEP 478
7.4.7 The Anthropocene 482
7.4.8 The technosphere 485

7.5 Power and group selection of technology 488
7.5.1 The role of the military in technological innovation 488
7.5.2 Power projection and social organization of means of violence 491
7.5.3 Red Queen effects in institutional group selection 494
7.5.4 A natural experimentum crucis: China vs. Europe 497

8. MARKETS 504

8.1 Performing the artefact of markets in human networks 504
8.1.1 Markets as evolving networks 504
8.1.2 Performativity of economics and ‘marketization’ 507
8.1.3 Markets in the context of general evolution 510

8.2 Markets as institutions: Uncertainty and networked valuation 513
8.2.1 Trust and the asset specificity of specializing on market opportunity 513
8.2.2 The fundamental problem of the uncertainty of comparative advantage 517
8.2.3 Prices and market clearing 519
8.2.4 Asset valuation, markets and networks 522
8.2.5 The institutional nature of market valuation 526
8.2.6 Market states as institutions 530

8.3 Power and the institution of money 532
8.3.1 Money and credit 532
8.3.2 Government and trust into money 534
8.3.3 The institution of credit 538
8.3.4 Trust and status in monetary evolution 542

8.4 Prices as social facts 545
8.4.1 The fundamental incompleteness of arbitrage 545
8.4.2 The complexity of collective price-setting 547
8.4.3 Reconsidering the simple supply and demand framework 550
8.4.4 Market clearing across many markets: Macroeconomics 554

8.5 Transactional capabilities and firms as market replicators 558
  8.5.1 Social capital and transaction enabling transactions 558
  8.5.2 Dimensions of networks and scope of market transactions 560
  8.5.3 Firms, markets and networks 564

8.6 Firms, markets and human labour 571
  8.6.1 Firms and the measurement of entrepreneurial input and corporate governance 571
  8.6.2 Limitations to mobility of labour and the performativity of incentive systems 573
  8.6.3 The performativity of incentive systems and wages as institutions 576

8.7 Markets and general evolution 584
  8.7.1 Money, credit and growth 584
  8.7.2 Market dynamics and entropic principles 587
  8.7.3 The growth of markets 591

References 596

Index 656