The Dynamics of Regions and Networks in Industrial Ecosystems

Edited by

Matthias Ruth

Brynhildur Davidsdottir

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Matthias Ruth

University of Maryland, College Park, Maryland, USA

Brynhildur Davidsdottir

University of Iceland, Reykjavik, Iceland

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Contributors

Peter M. Allen, BSc PhD is Head of the Complex Systems Research Centre in the School of Management at Cranfield University. He is part of the PhD and DBA programme at Cranfield and is an Invited Professor on the PhD Programme in the Economics Department of the University of Paris I, as well as contributing to Masters and Doctoral programs at Warwick and Aston Business Schools. He is an Editor in Chief of the journal *Emergence: Complexity and Organization*. He is currently running a large ESRC research project jointly with Sheffield University studying the use of complexity science to understand the evolution of the supply chain of aerospace companies. His research is directed towards the application of the new ideas concerning evolutionary complex systems to socio-economic sustainability, resilience and security. He has a PhD in Theoretical Physics and from 1970 to 1987 worked with Professor Ilya Prigogine at the Université Libre de Bruxelles. He has written and edited several books and published well over 200 articles in a range of fields including ecology, social science, urban and regional science, economics, systems theory and physics. He has been a consultant to the Defence Evaluation and Research Agency (DERA), the Civil Contingencies Secretariat, the Canadian Fishing Industry, Elf Aquitaine, the United Nations University, the European Commission and the Asian Development Bank. He has managed a number of large European and UK research contracts.

Lauren Basson is a lecturer at the Centre for Environmental Strategy (CES) within the School of Engineering at the University of Surrey, UK. Lauren holds BS and MS degrees in chemical engineering from the University of Cape Town, South Africa, and a PhD in chemical engineering from the University of Sydney, Australia. Her principal area of interest is decision support for complex decision situations. Prior to commencing with the PhD, Lauren worked as an environmental process engineer in an environmental consulting firm in Johannesburg, South Africa, where she consulted principally to the mining and minerals processing industries. She has also consulted extensively to the South African electrical utility (Eskom) on a range of projects including the selection of cleaner technologies for coal-based power generation, the screening of greenhouse gas reduction projects for the Clean Development Mechanism of the Kyoto Protocol and

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the incorporation of sustainability considerations into the performance evaluation of senior management.

Tim Baynes has led a diverse career in applied physics, publishing in international journals on magnetics and biophysics and completing a PhD in applied physics from the University of New South Wales in 2002. In recent years he has turned his attention to industrial ecology, complex systems science and sustainability analysis and currently works as a systems analyst within the Urban Systems Program of the Commonwealth Scientific and Industrial Research Organisation (CSIRO)'s Sustainable Ecosystems Division. The research activities Dr Baynes undertakes include the material and energy accounting of the physical economy and the application of complex system dynamics to problems of urban function and development.

Paul Beavis is currently a doctoral candidate with the School of Civil and Environmental Engineering at the University of New South Wales. He graduated with an Honors degree in environmental engineering (water) in 2001. While pursuing his degree he worked with Sydney Water Corporation in their wastewater planning section on reviews of plant augmentation. Since graduation he has worked for the Centre for Water and Waste Technology in the field of environmental life cycle assessment (LCA). Projects he has been involved with have entailed sustainability assessments of centralized and decentralized water and wastewater plants and solid waste treatment processes and logistics.

His PhD thesis topic deals with service in transportation infrastructure as a means to reduce material and energy throughput of the Australian economy. His case studies focus on developing smart infrastructure hubs (intermodal terminals and their production systems) in the Sydney basin as an attempt to reconcile logistics demands and infrastructure supply in the container freight and the waste management industries respectively.

Clark Bernier, at the time of writing, was an assistant faculty researcher at the University of Maryland's School of Public Policy. In addition to developing PowerPlay (an interactive energy efficiency role-playing game), he has worked with the University of Massey in New Zealand on the Climate's Long-Term Impacts on New Zealand Infrastructure (CLINZI) model and with the Joint Global Change Research Institute to develop a model of US power plant and transportation equipment retirement. He has a Masters of Public Policy from the University of Maryland and a BA in Political Economy from Knox College. He currently works as an efficiency program evaluation analyst in Sonoma, California.

John A. Black is a Professor in the Planning Research Centre at the University of Sydney and Director of the University of New South Wales

(UNSW), Botany Bay Studies Unit – a transdisciplinary research center that researches sustainability issues of the bay and its urbanized hinterland. He is a visiting professor in the Graduate School of Environmental Studies, the Laboratory for Sustainable Transport and Spatial Development at Nagoya University, Japan. He was Foundation Professor of Transport Engineering at the UNSW from 1984–99. He earned his PhD in transport engineering from Bradford University, a Masters in urban and regional planning from Sydney University, and a BA with Honors in urban geography from Manchester University.

Since 1968, he has undertaken research on land use, transport and the environment, and has an international reputation in transport planning and the economic, social and environmental impacts of transport infrastructure and services. He specializes in strategic planning and has advised government on numerous futures studies. Dr Black has acted for over 25 years as a high-level consultant to international agencies, such as the World Bank and the United Nations Development Programme, the Australian Commonwealth, state and local government agencies, and to the private sector and community groups.

Marian R. Chertow is Associate Professor and Director of the Industrial Environmental Management Program in the Center for Industrial Ecology at Yale University's School of Forestry and Environmental Studies. Broadly, her interests focus on industrial ecology and industrial symbiosis, environmental technology innovation, and business–environment issues. Her research focuses on evaluating public and private benefits of cooperative environmental business practices at the interfirm level and, ultimately, whether and how these practices might foster a shift to environmental sustainability. Professor Chertow came to Yale following ten years in state and local government and environmental business where she specialized in waste management.

Gyorgyi Cicas has a PhD in civil and environmental engineering from Carnegie Mellon and an MS in environmental engineering from the University of Pannonia, Hungary. She has worked as a trainer and consultant for TEQUA International (2000–02) and as a project manager of the Pollution Prevention and Environmental Management System Consultation project (1998–2000).

Brett Cohen holds both BS and PhD degrees in chemical engineering from the University of Cape Town, South Africa. He is currently employed as a part-time Senior Research Fellow at the University of Cape Town, and as Partner in the GreenHouse Consultancy in Cape Town. He has a wide range of experience in environmental management and sustainability strategy issues, having worked both in academia and in the private sector. His current work focus includes the development and implementation of tools for the support of complex decision-making and strategic planning towards sustainable outcomes in industrial and infrastructure networks.

Brynhildur Davidsdottir is Associate Professor of Environment and Natural Resources at the University of Iceland, and is the Director of the Graduate Program in Environment and Natural Resources. Before joining the University of Iceland in 2006, Dr Davidsdottir was an associate at Abt Associates Inc., Cambridge, Massachusetts, and a lecturer at Boston University. Much of her research has focused on complex systems modeling of resource and environmental policy issues, such as regional responses within the United States to various climate change policy options and the impact of those responses on the natural environment; adaptation of different cultures to changes in their external economic and natural environment as exhibited through natural resource use and management; and the development of sustainable energy development indexes.

Gerard P.J. Dijkema is Associate Professor of Energy and Industry, Delft University of Technology, Department of Technology, Policy and Management. In research and education he specializes in innovation for sustainability in industry and infrastructure networks, notably the understanding, development and transition of large-scale socio-technical systems. Drawing from technology, policy and management, his research involves model-based decision support, to help stakeholders to develop sustainable policies and strategies. By general election he is a member of the general council of the water authority Hoogheemraadschap van Delfland. An active advisor to regional and national authorities and companies, he has (co-)authored more than 100 papers and reports, among which are four patents and a dozen journal papers. Dr Dijkema graduated as a chemical engineer (Hons) and holds a PhD from Delft University of Technology.

John R. Ehrenfeld is Executive Director of the International Society for Industrial Ecology. He currently serves on the Council of the Society for Organizational Learning. His current research focus is on sustainability and culture change. A book on this subject is forthcoming in 2009 from the Yale Press. He retired in 2000 as the Director of the MIT Program on Technology, Business and Environment. In October 1999, the World Resources Institute honored him with a lifetime achievement award for his academic accomplishments. He holds a BS and ScD in Chemical Engineering from MIT, and is author or co-author of over two hundred papers, books, reports and other publications

Blanca Gallego completed her PhD in atmospheric and oceanic sciences at the University of California, Los Angeles, after which she joined the Centre for Integrated Sustainability Analysis at the University of Sydney, where she undertook research on environmental accounting systems, regional input–output economics and corporate sustainability reporting. Currently Dr Gallego is a Research Fellow at the Centre for Health Informatics at the University of New South Wales where she works on surveillance models of infectious diseases and decision support tools for clinicians and public health practitioners in the context of infectious disease management.

Chris T. Hendrickson is Duquesne Light Company Professor of Engineering and Co-Director of the Green Design Institute at Carnegie Mellon University. His research, teaching and consulting are in the general area of engineering planning and management, including design for the environment, project management, transportation systems, finance and computer applications. He has co-authored five books: *Environmental Life Cycle Assessment of Goods and Services: An Input–Output Approach* (Resources for the Future 2005), *Project Management for Construction* (Prentice-Hall 1989), *Transportation Investment and Pricing Principles* (John Wiley & Sons 1984), *Knowledge Based Process Planning for Construction and Manufacturing* (Academic Press 1989) and *Concurrent Computer Integrated Building Design* (Prentice-Hall 1994).

Ruud Kempener is a Research Fellow at the Energy and Environment Programme at SPRU – Science and Technology Policy Research, University of Sussex (UK). Ruud completed his PhD in the Complex Systems and Sustainability group of the School of Chemical and Biomolecular Engineering at the University of Sydney in 2008, and has an MS degree in technology and innovation policies from the Eindhoven University of Technology, the Netherlands. Ruud uses agent-based modeling to explore the consequences of individual behavior, business strategies and policy interventions on the sustainable development of supply chain and industrial network evolutions in the energy sector, chemical industries and agriculture.

John 'Skip' Laitner is a resource economist with more than thirty years of experience in science and economic impact studies, public policy analysis, and economic development planning. He currently serves as Senior Economist at the American Council for an Energy-Efficient Economy. He was awarded the EPA's 1998 Gold Medal for his work with a team of EPA economists that helped lay the foundation for the recent Kyoto Protocol on Greenhouse Gas Emissions. In 2003 he was acknowledged as a technology leader when given the 'CHP Champion' award by the US Combined Heat and Power Association.

James Lennox currently holds a research position at Landcare Research New Zealand Ltd. His research interests include environmental input–output analysis, the application of full cost accounting and other techniques to assess sustainability within organizations, and research into the impacts of tourism in New Zealand. Previously, Dr Lennox worked as a postdoctoral fellow at CSIRO Sustainable Ecosystems, Australia. In that position he helped to develop a stocks-and-flows model of the Australian economy, concentrating on industrial production processes. He also studied material and energy flows associated with Australian towns and cities, as well as the accumulation of cadmium in agricultural systems. Dr Lennox has a PhD (2002) and a Bachelors of engineering (chemical, with Honors, 1997) from the University of Queensland, Australia. His doctoral research concerned applications of multivariate statistical techniques to the detection of faults in biological wastewater treatment and verification of computer simulation models.

Manfred Lenzen is Professor of Sustainability Research at the Centre for Integrated Sustainability Analysis of the University of Sydney. After completing a PhD in nuclear physics at the University of Bonn in Germany, Professor Lenzen moved to Australia where he took up work on renewable energy technologies (solar-thermal electricity, passive solar architecture and wind turbines) at the University of Sydney. At present, Professor Lenzen works on the development of quantitative methods for integrated triple bottom line accounting, dynamic modeling of greenhouse gas emissions, land use and biodiversity, and multi-criteria decision analysis. Prof Lenzen has published nine book chapters and more than 60 articles in international peer-reviewed journals. He has worked as Visiting Professor at the University of Tokyo and the Federal University of Rio de Janeiro, and collaborates extensively with research groups in the UK, Japan, Brazil, the United States, Denmark, Norway and Germany. He is Chief Editor for the *Journal of Industrial Ecology and Economic Systems Research.*

Shannon M. Lloyd is a Principal Technical Advisor in Concurrent Technologies Corporation (CTC)'s Sustainability and Process Engineering Directorate. Dr Lloyd's research focuses on evaluating advanced or emerging technologies that can contribute to energy efficiency and security, environmental sustainability and pollution prevention. Of particular interest is using quantitative analysis and mathematical modeling to assess the economic and environmental implications of policy and investment decisions. Dr Lloyd has experience applying life cycle assessment, risk assessment, energy modeling and greenhouse gas accounting in a variety of industry and government settings. She is currently conducting research to incorporate quantitative uncertainty analysis, spatial differentiation and temporal differentiation in environmental life cycle assessment. Dr Lloyd received a PhD in engineering and public policy and an MS in civil and environmental engineering from Carnegie Mellon University and a BS in general engineering from the University of Illinois at Urbana-Champaign. Prior to joining CTC, she held positions at John Deere Harvester Works, Square D Company, and First Environment.

H. Scott Matthews is an Associate Professor of Civil and Environmental Engineering, and Engineering and Public Policy, at Carnegie Mellon University. He is also the Research Director of the Green Design Institute. His primary research interest is sustainable life cycle management of infrastructure, where infrastructure includes transportation and building facilities, as well as energy, utility and telecommunications networks. In assessing the efficiency of management methods, he considers private and social aspects such as externality costs of pollution.

Alan Meier is Senior Scientist at the Lawrence Berkeley National Laboratory. Dr Meier earned degrees in chemistry and economics, and a PhD in Energy and Resources from the University of California, Berkeley. Most of his research has dealt with understanding how energy is used and how it could be used more efficiently. His work relies heavily on field measurements of the energy use of buildings and equipment. About a decade ago he began to study the energy consumption of 'miscellaneous' equipment and, more recently, the energy use of appliances when they were switched off. This research sparked his interest in standby power and launched an unusually successful global effort to reduce standby power in all sorts of equipment. Dr Meier has published over one hundred papers and articles in journals, magazines and conference proceedings, mostly about energy efficiency. He founded the magazine *Home Energy*, and served as Editor-in-Chief of the journal *Energy and Buildings*. This chapter describes research undertaken while Dr Meier was a senior energy analyst at the International Energy Agency in Paris.

Stephen J. Moore has 12 years of experience in the public sector and private consulting in the fields of solid and hazardous waste management, and environmental management. He has a Bachelors degree in engineering (civil, with Honors) from the University of New South Wales (UNSW) and a Masters in engineering science from Adelaide University. He has been responsible for the preparation of environmental impact statements, reviews of large companies' environmental performance, creation of regional solid and hazardous waste management strategies, the design of transfer stations, recycling schemes, landfills and hazardous waste treatment plants.

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In 1991 he joined the UNSW as Senior Lecturer in Waste and Environmental Management, where he is now Director of Studies, Environmental Engineering. He also coordinates and is principal lecturer for the coursework Masters degrees in waste management and environmental engineering. His research activities include the establishment of a national waste database for Australia and the development of analytical and design tools for improved environmental management at the corporate and regional level. This includes use of materials accounting tools such as life cycle assessment, material flow analysis, sustainable process index, ecological footprints, and total material requirements.

Igor Nikolic graduated as a chemical and bio-process engineer from Delft University of Technology. In his MSc thesis he presented an agent-based model of gene flow from genetically modified (GM) crops to surrounding plant populations. After his graduation, he spent several years as an environmental researcher and consultant at University of Leiden, Institute for Environmental Science (CML), where he worked on life cycle assessment/material flow analysis (LCA/MFA) and industrial ecology. In his research he specializes in applying complex adaptive system theory and agent based modeling of network evolution and industry–infrastructure networks. He is an active promoter of open source software and social software that enables group work and collaboration and has (co-)authored some 20 publications. Currently, he is completing his PhD at the Energy and Industry Group, Faculty of Technology, Policy and Management, Delft University of Technology.

Jim Petrie is Emeritus Professor of Chemical Engineering at the University of Sydney, and Honorary Professor at the University of Cape Town, South Africa. At Sydney, he leads a research group whose interests are centered on engineering for sustainability. Specific focus areas include environmental systems analysis based on life cycle thinking, decision support for complex decisions characterized by multiple objectives under risk and uncertainty, process modeling, and technology development. Much of this work has been in support of primary industries and infrastructure, including minerals and metals, power generation, water and waste industries. He consults widely to the resources sector in both South Africa and Australia. He is a Chartered Engineer in the UK and a Fellow of the Institution of Chemical Engineers.

Robert Ries is the Rinker Professor of Construction, Assistant Professor and Associate Director of the Powell Center for Construction and the Environment in the M.E. Rinker Sr School of Building Construction at the University of Florida. Dr Ries's primary research work is focused on improving the environmental performance of buildings and the built environment. His work includes environmental life cycle assessment (LCA) in the building domain, LCA studies of building systems, modeling construction processes, and building process modeling. His research also addresses developing LCA methodology, such as incorporating optimization, managing uncertainty, and assessing impact at variable temporal and spatial scales. Dr Ries has developed courses in green design and construction and sustainable development that are both required and elective courses in the undergraduate and graduate programs in the School.

David L. Rigby is a Professor in the Departments of Geography and Statistics at the University of California, Los Angeles. He received his MA and PhD in geography from McMaster University, Canada. His research interests include economic geography, technological change, evolutionary economics, regional growth and uneven development, political economy, and spatial statistics. Dr Rigby has published two books and more than 50 journal articles and book chapters.

Matthias Ruth is Roy F. Weston Chair in Natural Economics, Professor and Director of the Environmental Policy Program at the School of Public Policy, Director of the Center for Integrative Environmental Research at the Division of Research, and Co-Director of the Engineering and Public Policy Program at the University of Maryland. His research focuses on dynamic modeling of natural resource use, industrial and infrastructure systems analysis, and environmental economics and policy. His theoretical work draws heavily on concepts from engineering, economics and ecology, while his applied research utilizes methods of non-linear dynamic modeling as well as adaptive and anticipatory management. Dr Ruth has published 12 books and more than 100 papers and book chapters in the scientific literature. He collaborates extensively with scientists and policy makers in the USA, Canada, Europe, Oceania, Asia and Africa.

Graham M. Turner currently works on whole-of-system analysis involving whatIf coding of the Australian stocks-and-flows framework, capturing historical data and creating scenarios of Australia's future, and communicating these analyses to others. Topics have included Australian agriculture, fisheries, transport, and climate change impacts. He leads a small team developing an urban metabolism framework. At the global level, his research involves scrutinizing scenarios of the global socio-economic system, particularly those of the limits to growth. Dr Turner has earned his PhD in physics from the University of Sydney, Australia, modeling and measuring ionized gases used to create thin metallic films. He is now with CSIRO Sustainable Ecosystems searching for physically sustainable futures at the city, state, national and global levels.

Koen H. van Dam is a researcher and PhD candidate in the Energy and Industry Group, Faculty of Technology, Policy and Management, Delft University of Technology. Working on the topic of modeling infrastructures as multi-agent systems, his main research interests include intelligent infrastructures, multi-agent and complex systems, ontology design, knowledge acquisition, electricity infrastructure and industrial networks. A (co-) author of a dozen publications, Koen van Dam holds a Masters degree in knowledge engineering from the VU University, Amsterdam.

Jim West has a background in geology and computing, and now works as a systems modeler in the Urban Systems Program of CSIRO's Sustainable Ecosystems Division. He is interested in simulation and modeling tools generally, the applicability of such tools to enumerating and visualizing the physical outcomes of different development paths, and the question of how such physical outcomes might meaningfully be linked to estimating the subjective well-being of affected populaces.

Foreword

John R. Ehrenfeld

With this book, Matthias Ruth and Brynhildur Davidsdottir have made an important and substantial contribution to the still evolving field of industrial ecology. In the years that have transpired since the emergence of the idea that economic and industrial systems generally exhibit features analogous to natural ecosystems, the field has taken root. Industrial ecology now has associated with it activities in many universities, consultants with programmes based on industrial ecological principles, and applications of these principles showing up in corporate strategy, product design and public policy. The key principles spring from the above-mentioned ecological analogy and include such notions as loop closing and symbiosis, mimicking forms and processes found in *healthy* ecologies. The first chapter in the collection expands and comments on connections between the field and natural ecosystems.

The stressed term above, 'healthy', lends a normative dimension to the field, beyond the merely descriptive character of analogies. Environmental management and its successor concept, sustainability, have become firmly embedded in high-level societal activities in virtually every economic sector and industrialized nation. The relevance of these terms is tied to a still-growing consciousness of the fragility of the Earth's ecosystem and its criticality as the primary life support system of our species and indeed all life. International consensus about global warming and its impact on climate has now heightened interest in acting to preserve the environment for the present and for future generations.

Among many potential pathways toward sustainability, one stands out as the choice of most industrial and governmental strategies: eco-efficiency. Eco-efficiency, the idea of providing more value for less impact, is contained in many other prescriptive statements, such as dematerialization, decarbonization, detoxification, factor X reduction, cradle-to-cradle, and so on. Healthy ecosystems are naturally 'eco-efficient'. They recycle the nutrients found in their local environment by closing material loops. Detritivores turn the wastes produced in the food web into nutrients for species in other places in the web. The source of energy is renewable solar energy. It is only a very small jump to get from this observation to a normative possibility for industrial ecology: produce a more sustainable world by designing economic and industrial systems to look and behave more like ecosystems.

This possibility has taken hold in several important areas, for example, in the design of technological artifacts (design for environment) and in the design of industrial organization (eco-industrial development). In both of these cases, analytic and design tools, based on material and energy flows, have been developed and applied. Other analytic models and tools have been developed for larger systems, such as national or regional material economies (flows), but these have not achieved the level of design applications as the above two cases. It would seem, based on a patently unscientific assessment by this author, that the 'simpler' the system, as in product systems, the more the ideas of industrial ecology have found their way into practice. 'Simple' in this sense has several aspects, temporal and organizational. Products generally have shorter lifetimes than industrial systems, especially looking at common consumer products such as automobiles, mobile phones or computers.

The present generation of industrial ecological models and tools largely springs from relatively static analyses. The assumptions that are made in applying the tools generally assume that the context of the analysis approximates the conditions during the actual lifetime of the system under the analyst's lens. These tools also generally do not take into account sociological and organizational processes that are involved in putting the prescriptions into play. Again, for product systems, this limitation is not critical as to technical considerations although it is part of the reasons that the outcome that the designer or strategist had in mind may turn out differently.

Furthermore, these first generation models are almost exclusively based on assumptions of linearity with respect to the technical components and on normal rationality with respect to the human elements, in those cases where consideration of actor behavior enters the analytic framework. And finally, much of the work reflects the reductionist nature of the technical disciplines on which industrial ecology rests. This statement should not be read as a criticism of this sociological fact, but merely as an argument for expanding the intellectual basis for what has been the mainstream of research and analysis within industrial ecology.

If one stops for a moment and thinks about the more complex situations mentioned above, the next generation of analytic and design tools will have to incorporate models of processes that more realistically reflect the messy way that the world does, unfortunately for analysts, really work. As the editors of this volume point out, this requires that new ideas must be injected into industrial ecological thinking and research. For example, ways to account for changes in material stocks over long periods are now being incorporated into frameworks for analyzing material flows in large and long-lasting systems, as several chapters indicate.

Readers who have read my recent writings know that I believe that the limits of the present linear models, including those representing ecosystem processes, correspondingly limit the ability of the workers in the field to muster convincing arguments that industrial ecology can be a powerful new frame for thinking about and acting towards sustainability. Eco-efficiency thinking is extremely important in revealing ways to stop and even reverse the apparently inexorable trajectory towards breakdown and destruction of the natural world, with consequent immense potential social implications. But eco-efficiency, like efficiency in any setting, ignores possible absolute limits to growth. William Jevons, writing in 1865, noted that coal consumption in England eventually rose in volume even after the large increase in efficiency produced by Watt's steam engine. Jevons's notion lives today in the current notion of the rebound effect which implies that eco-efficiency (creating wealth in the process) will produce more investment and more consumption, eventually outstripping any gains from technological improvements.

Several of the chapters in this book delve into the area of complexity, invoking new models for the evolution of technical and associated human systems. This work helps make clear the important distinction between the complicated and the complex. The kinds of systems of interest to industrial ecologists have always been complicated, involving many interwoven processes, but processes that have been examined as separate pieces of the overall puzzle and with linear analytic bases. Typical product systems that have been examined often have hundreds of components and many tens of distinct materials involved, producing impacts on various environmental media in different places and times. Certainly not simple, but not complex. Complexity is reserved for systems that cannot be effectively analyzed by such reductionist methods. The key outcomes are the results of interconnected, often non-linear processes that cannot be reduced to analytic statements. Such systems may exhibit unpredictable and discontinuous behavior, possibly flipping from healthy regimes to unsustainable states. Human behavior and its role in establishing the dynamics of such systems cannot be modeled on standard concepts of rationality, even using Simon's notion of bounded rationality. The typical assumptions of stable preferences must be relaxed because the time frames involved are much longer than present models comfortably allow.

Models based on complexity foundations are much more likely to lead to more effective applications in dynamic circumstances, the primary setting for this book as the title denotes. This contextual feature is important when

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