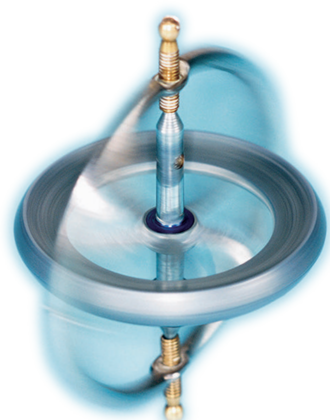
Second Edition

STRATEGIC MODELLING and BUSINESS DYNAMICS

A feedback systems approach



John D. W. Morecroft

WILEY

‘Much more than an introduction, John Morecroft’s *Strategic Modelling and Business Dynamics* uses interactive “mini-simulators and microworlds” to create an engaging and effective learning environment in which readers, whatever their background, can develop their intuition about complex dynamic systems. The examples, from manufacturing operations to competitive strategy, corporate growth and environmental sustainability, provide a rich test-bed for the development of the systems thinking and modelling skills needed to design effective policies for the strategic challenges faced by senior managers throughout the economy today.’
John Sterman, Jay W. Forrester Professor of Management, MIT Sloan School of Management

‘We are living in a world revolutionised by six decades of exponential growth in computing speed, where powerful computers have become consumer electronics and simulation has become virtual reality. Business modelling has come of age. This book, with its vivid examples and simulators, is helping to bring modelling, system dynamics and simulation into the mainstream of management education where they now belong.’
John A. Quelch, Professor of Marketing, Harvard Business School, Former Dean of London Business School

‘John Morecroft’s book is an ideal text for students interested in system modelling and its application to a range of real-world problems. The book covers all that is necessary to develop expertise in system dynamics modelling and through the range of applications makes a persuasive case for the power and scope of SD modelling. As such, it will appeal to practitioners as well as students. At Warwick we have a range of undergraduate, masters and MBA courses in simulation, business modelling and strategic development/planning and the text would provide valuable support to those courses.’
Robert Dyson, Emeritus Professor, Operational Research and Management Sciences Group, Warwick Business School

‘Illustrated by examples from everyday life, business and policy, John Morecroft expertly demonstrates how systems thinking aided by system dynamics can improve our understanding of the world around us. Indeed, such thinking provides the basis for improving our world, from making everyday decisions to leading key strategic and policy initiatives. Anyone who is interested in understanding the world and making better choices should read this book.’
Stewart Robinson, Associate Dean Research, President of the Operational Research Society, Professor of Management Science, School of Business and Economics, Loughborough University

‘This text fills the gap between texts focusing on the purely descriptive systems approach and the more technical system dynamics ones. I consider it particularly well suited to the more mature student (MBA, EMBA, Executive courses) due to the focus on conceptualisation and the understanding of complex dynamics.’
Ann van Ackere, Professor of Decision Sciences, HEC Lausanne, Université de Lausanne

‘In today’s complex business world company leaders are repeatedly challenged to rethink dominant strategic logics, and if necessary to adapt their firms to cope with turbulence and change. Strategic modelling based on system dynamics is a powerful tool that helps to better understand the feedback structures underlying the dynamics of change. The author demonstrates the appeal and power of business modelling to make sense of strategic initiatives and to anticipate their impacts through simulation. The book offers various simulators that allow readers to conduct their own policy experiments.’
Dr Erich Zahn, Professor for Strategic Management, University of Stuttgart

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A Feedback Systems Approach

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To Jay Forrester, academic pioneer

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About the Author

John Morecroft is Senior Fellow in Management Science and Operations at London Business School where he has taught system dynamics, problem structuring and strategy in MBA, PhD and Executive Education programmes. He served as Associate Dean of the School's Executive MBA and co-designed EMBA-Global, a dual degree programme with New York's Columbia Business School. He is a leading expert in system dynamics and strategic modelling. His publications include numerous journal articles and three co-edited books. He is a recipient of the Jay Wright Forrester Award of the System Dynamics Society for his work on bounded rationality, information feedback and behavioural decision making in models of the firm. He is a Past President of the Society and one of its Founding Members. His research interests include the dynamics of firm performance and the use of models and simulation in strategy development. He has led applied research projects for international organisations including Royal Dutch/Shell, AT&T, BBC World Service, Cummins Engine Company, Ford of Europe, Harley-Davidson, Ericsson, McKinsey & Co and Mars. Before joining London Business School he was on the faculty of MIT's Sloan School of Management where he received his PhD. He also holds degrees in Operational Research from Imperial College, London and in Physics from Bristol University.

Foreword by Peter Checkland

When I was a manager in the synthetic fibre industry in the 1950s and 60s, there was a recognised but problematical pattern of activity in the textile industry. A small increase in demand for textile products would induce big ups and downs back in yarn and fabric production. This arose as a result of the structure of the production-to-retail chain, a sequence from fibre to yarn to fabric to products, these being stages in the hands of different companies between which were time delays. This recurring pattern of response to demand change was one which no one stakeholder could command and control.

Many areas of human activity reveal dynamics of this type, with several classic patterns of behaviour: exponential growth or decline; oscillation; S-shaped growth; growth followed by collapse, etc.

John Morecroft's textbook is a brilliantly clear guide to elucidating and modelling such patterns of behaviour. The modelling is normally a team effort based on both real-world experience of the area and the principles of system dynamics. Such modelling seeks to reveal enduring feedback structures (both balancing and reinforcing) which are real characteristics of the situation in question but are normally hidden. Once developed, such models are 'instruments for investigation, clarification and discovery', and can be used to feed better evidence into discussion of strategy than does the reliance on experience and gut feel, which is the common mode of managing.

These pictures of dynamic behaviour may be relevant within an organisation (public or private) or may be characteristic of an industry. A particularly interesting example in the book is the one which in the end affects us all – the dynamics of the oil industry. Here is complexity stemming from an oil market which tries to meet demand, a fluctuating price for oil, an organisation of some producers (OPEC) which sets quotas for production and suppliers consisting of independents, opportunists and a 'swing producer' (Saudi Arabia), which produces just enough to defend OPEC's intended price. The build-up of the model of industry dynamics is lucidly described. It was carried out not as an academic exercise but by the author working with a team of Shell managers, and made a serious contribution to Shell's strategic thinking about their industry context and its possible futures.

This illustrates an outstanding feature of John Morecroft's approach. All the work described was carried out in active engagement with managers facing problems.

Not for this author the too-familiar picture in which academics sit at their desks and write papers about other papers!

So this book is not 'academic' in the usual derogatory sense of that word. Nor is it a book to be read casually in an armchair, for it comes with website materials enabling readers to get a feel for situation dynamics by running simulators – including one containing the oil industry model.

Finally, although presented as a textbook, this volume is relevant on a broader canvas. When I was a manager in industry I found the then textbook management science irrelevant to my day-to-day concerns. However, since then a major shift in perspective has occurred. Originally the core concept ('hard') was to make models of assumed real-world systems, and then experiment on the models to find optimum ways of doing things. The richer current concept ('soft') illustrated here, is complementary to this. It uses models as transitional objects to aid learning. In his last chapter John Morecroft writes:

> The idea that there is a singular and objective world out there to be modelled is replaced with the softer notion that a formal model can help improve mental models … through which we interpret and make sense of the world …

For its lucidity, its practicality and its illustrations of the idea of consciously learning your way to 'action to improve', this book is a very welcome addition to the literature. It brings a fresh wind off the heath to the groves of academe.

Peter Checkland
Emeritus Professor of Systems
and Honorary Fellow
of Lancaster University

Preface to the Second Edition

In the second edition of *Strategic Modelling and Business Dynamics* I have refreshed the book while building on its strengths. The original 2007 book was well received. So I retained the pre-existing ten-chapter architecture and within this architecture I made numerous chapter-by-chapter revisions. For example chapters 1 and 9, on the fishing industry and *World Dynamics* refer to new research and web-based simulators about sustainability and climate change. The background to the oil industry in Chapter 8 reports changes to industry structure and the advent of shale oil. The references at the end of each chapter have been carefully reviewed and updated to include selected journal articles and books that point the way to important ongoing developments in the field such as group model building and computationally intensive analytical methods.

But there is more too. I want the book to be an enduring bridge from traditional to contemporary system dynamics, and so I have created two accompanying websites – the Learners' website and the Instructors' website.[1] Traditional system dynamics involves a distinctive 'style' of modelling and analysis. It lays strong emphasis on clear visualisation and documentation of real-world feedback structure backed-up by rigorous yet easy-to-read equation formulations. Understanding of dynamics comes from careful narrative interpretation of simulations. I use these style guidelines for modelling and analysis throughout the book and I believe it is important for all students of system dynamics to master them. To reinforce the message I have provided, on the Learners' website, selected articles from the working paper archives of the MIT System Dynamics Group.[2] I hope readers will enjoy these historical glimpses of the field. On the Instructors' website I have provided annotated and graded solutions to course assignments showing exemplary work by students who have followed the style guidelines. My thanks to Chris Baker, Zahir Balaporia, Bill Grace and John Kapson (graduates of WPI's online programme in system dynamics) for agreeing to display their anonymised assignments for the benefit of other learners. It is worth noting that, when

[1]Please see the About the Website Resources section at the back of the book.

[2]The articles are reproduced with permission of MIT's Technology Licensing Office. They come from a special DVD archive collection of all the working papers and PhD theses in the D-memo series of MIT's System Dynamics Group, covering a period of almost 50 years, starting in the early 1960s. In total the collection contains around five thousand articles, originally printed on paper, which have each been scanned to create electronic pdf files. Copyright of the entire collection resides with MIT and the DVD is available from the System Dynamics Society www.system dynamics.org.

enrolled in the course, they each held responsible full-time posts in business or government.

From this foundation of rigour-with-accessibility it is then possible for learners to reach out securely to complementary methods and ideas, whatever form they might take. For example, the book already connects with contemporary behavioural and resource-based views of the firm, as described in the Preface from the 1st Edition of the book (see the next section). These ideas, from modern economics and strategy, fit neatly with asset stock accumulation and the *information feedback view of the firm* found in traditional system dynamics. In addition, and scattered throughout the book, there are references to contemporary analytical methods for dynamic models. And finally, for model conceptualisation, there is mention of tried-and-tested protocols for group model building.

I have added two new electronic topics that can be found in learning support folders on the Learners' website (see the About the Website Resources section). The topics are the 'dynamics of diversification' and 'managing metamorphosis'. Diversification is an important part of corporate (multi-business) strategy and complements material in Chapters 6, 7, 8 and 10 on the dynamics of single-business firms and of entire industries. Metamorphosis is a process of managed adaptation to change in the business environment; change that is often ushered in by firms, industries and societies as they co-exist and innovate while competing for resources and markets. When the environment changes organisations must reliably sense the change. Then they must take timely action to re-configure their assets and operating policies in order to survive and contribute to the formation of a new and beneficial future environment. The material on metamorphosis is novel and somewhat experimental. It can be seen as a way to extend the range of strategic modelling to include surprise disruption to firms' core business arising from technical and social innovations – and covert side-effects. The new electronic content includes video lectures from my online course at Worcester Polytechnic Institute (WPI). I am grateful to Khalid Saeed and Jim Doyle at WPI for enabling and supporting the use of this video content.

All the simulators used in the book are now stored on the Learners' website in chapter-by-chapter learning support folders. They are accompanied by an evergreen link to the latest iThink modelling software. My thanks to Karim Chichakly at isee systems for providing this link and for implementing, within the evolving software, special functionality on which my book relies – in particular sketchable time charts and the capability for users to conduct instructive 'tours' of initial simulator conditions (by hovering-over model icons to view the numerical values they hold).

My thanks also to the editorial and book production team at Wiley for their friendly and professional support throughout the 2nd edition project. Jenny Ng worked diligently with me on design and content changes. She also expertly managed permissions and ensured everything was completed on time. Tessa Allen skilfully guided the book through it's multi-stage production process while Caroline Quinnell sharpened numerous phrases during copy editing. My secretary Suzanne Shapiro has steadfastly and cheerfully supported my work at London Business School for more than 25 years. During this period Suzanne and I have been based in two different subject areas: Strategy & Entrepreneurship (1986–1996); and Management Science & Operations (1997–present). Thank you Suzanne! Finally, I thank my wife Linda who provides the motivation, love, stability and perspective of family life that lies behind all my work.

Preface from the First Edition[3]

I first became interested in models and modelling when I studied physics as an undergraduate at Bristol University. Or perhaps my interest was really awakened much earlier when, as a boy of nine or 10, my friend Alan Green introduced me to the board game of Monopoly. I soon became fascinated with board games of all sorts and accumulated a collection that included Cluedo (a detective murder mystery game, also known as Clue), Railroader (a game to build and operate your own wild-west railroad in competition with rival railway companies), and Buccaneer (a game of pirate ships and treasure collecting). I was intrigued by the colourful tokens, the chance cards, the rules and the evocative boards that showed city sights, a murder mansion, a treasure island or whatever was needed to fire the imagination. In Buccaneer, the game's clever distinction between the 'sailing power' and 'fighting power' of a treasure-seeking frigate is something I still appreciate today. And as a modeller I admire the game designer's artful representation of a pirate's world, set out on a blue-and-white chequered board that serves as an ocean.

Later, after graduating from Bristol, I joined Ford of Europe's operational research department, where computational decision models replaced the abstract and elegant models of physics. There I worked on investment appraisal (justifying the decision to build a new Fiesta car factory in Spain) and dealer location (whereabouts within Bromsgrove, Bury St Edmunds, or other English towns and cities, to site new car dealerships). During the second of my three years with Ford, the company sponsored me on an MSc degree in operational research at London University's Imperial College. It was at Imperial that I first encountered system dynamics, albeit briefly in an elective course on quantitative methods, and this chance encounter eventually led me to apply to the doctoral programme at MIT's Sloan School of Management for a PhD in system dynamics. Hence began the journey that I have pursued ever since.

When I look back over my 40-plus years in the field I see five different phases of work, all of which have contributed to the content of this book and led me to the friends and colleagues who have shaped my thinking. My names for these phases are: (1) manufacturing dynamics and information networks; (2) bounded rationality and behavioural decision making; (3) modelling for

[3]Full details of articles and books referred to in the Preface can be found in later chapters by cross-referencing with author names in the index.

learning; (4) the dynamics of strategy; and (5) soft systems and complementary modelling methods.

Manufacturing Dynamics and Information Networks

The first phase coincided with my doctoral dissertation at MIT when I worked on manufacturing and supply chain dynamics in Cummins Engine Company and Harley-Davidson. I was fortunate, back then, to have Jay Forrester as my PhD thesis supervisor, Jim Lyneis as a collaborator/faculty adviser on the Cummins project, and Nathaniel Mass as a faculty instructor. I learned many valuable modelling skills from them and from MIT's intensive academic apprenticeship with its special educational blend of theory and real-world practice. I still remember the sense of excitement as a first-year doctoral student, arriving by plane in Columbus Indiana, headquarters of Cummins Engine Company. There, I worked on the Cummins manufacturing dynamics project and found myself applying the inventory control, forecasting and production planning formulations I had learned at MIT. The simple factory model in Chapter 5 contains echoes of these same formulations. Further archive material on manufacturing dynamics can be found in the learning support folder for Chapter 5 on the Learners' website (see the About the Website Resources section).

My doctoral thesis topic arose from an on-the-job discovery that circumstance presented. I was working simultaneously on manufacturing models of Cummins and Harley-Davidson. When I set out the 10–15 page diagrams of these two models side-by-side on my apartment floor in Cambridge (Massachusetts), I noticed that the information flows which coordinated multi-stage production in the two factories were arranged in different patterns. Every stage of production in Harley, from final assembly of motorcycles to sub-assemblies and raw materials, was coordinated from a master schedule – a kind of top-down control. There was no such master schedule in Cummins's factory at the time. Stages of production followed local order-point rules. It turned out that Harley-Davidson was operating a computer-driven top-down material requirements planning (MRP) system, which was entirely new to manufacturing firms at the time (and, back then, had scarcely featured in the academic literature on operations management). My thesis compared the long-term dynamic performance of these alternative approaches to production planning and control. A striking result was that traditional order-point rules outperformed MRP (in terms of operating cost, production stability, inventory availability and lead-time predictability). Only under special and hard-to-achieve factory conditions was MRP superior, despite the cost-savings touted by advocates of MRP. And so my curiosity about information networks began.

As an aside, I should mention that the basis for the manufacturing models in my thesis was the production sector of the MIT group's National Economic Model. The production sector was essentially a generic model of the firm, residing within a system dynamics model of the US economy. The premise of the group's research at the time was that the US economy could be conceived as a micro-economic collection of interacting firms, households and banks. Macro-economic behaviour arises from micro-structure. Jay Forrester was leading the National Model project, so he knew the production sector intimately. As my thesis supervisor he was able to swiftly critique and guide my efforts to adapt this generic model of the firm to fit what I had discovered from the company-specific models of Cummins and Harley. I learned a great deal about model formulation and behaviour analysis from those encounters. I also learned from other doctoral students in system dynamics who, at the time, included David Andersen, Alan Graham, Mats Lindquist, Ali Mashayeki, George Richardson, Barry Richmond, Khalid Saeed and Peter Senge; and then later Nathan Forrester, John Sterman, Jack Homer, Jim Hines and Bob Eberlein.

It was while working with the production sector, which was a visually complex model, that I took to drawing boundaries around sets of model symbols that belonged with a given policy function, such as capacity utilisation or scheduling and ordering. This visual simplification procedure later led to policy structure diagrams as a high-level way of representing the coordinating network in system dynamics models. I use both policy boundaries and policy structure diagrams throughout the book.

Bounded Rationality and Behavioural Decision Making

My thesis showed that sparse and 'simple' information networks in firms can often deliver business performance that is superior to more complex and sophisticated information networks. This observation led me, as a newly-appointed junior faculty member at MIT Sloan, into the literature of the Carnegie School and Herbert Simon's work on bounded rationality. The idea that the 'structure' of a firm's information feedback network determines the firm's performance and dynamic behaviour is central to system dynamics.[4] The Carnegie literature helps to bring the information network into clear focus and to explain why human decision makers, faced with complexity and

[4]See also a guest lecture I delivered at WPI in 2009 entitled 'Reflections on System Dynamics and Strategy'. It can be found on the Learners' website in a folder entitled 'A Glimpse of Learning Phases in the Preface'. The same lecture can also be viewed on YouTube by searching under 'System Dynamics and Strategy'.

information overload, prefer sparse information networks. People and organisations are boundedly rational. They cannot gather or process all the information needed to make 'best' (objectively rational) decisions. Whenever people take decisions that lead to action, they selectively filter information sources, disregarding or overlooking many signals while paying attention to only a few. Well-designed policies recognise this human trait, while functional 'stovepipes' are an unfortunate corollary that stem from poor design (or no design at all). In practice, bounded rationality leads to departmentalised organisations in which the left hand quite literally doesn't know (and shouldn't need to know) what the right hand is doing. Loose coordination among functions, departments or sectors is normal.

Bounded rationality helped me to identify, interpret and better understand information feedback loops in business and social systems. Puzzling dynamics nearly always arise from 'hidden' coordination problems and this idea is woven throughout the book, beginning with the simple fisheries model in Chapter 1, continuing in Chapter 4's world of showers and in Chapter 5's factory model, and culminating in Chapter 7's market growth model. The information/coordination theme continues in Chapter 8 (the oil industry), in part of Chapter 9 (a return to fisheries) and in Chapter 10 (product growth dynamics in fast-moving consumer goods).

I was not alone at MIT in working on bounded rationality and system dynamics. John Sterman too was studying the topic, and using it to make sense of long-term economic cycles generated by the National Economic Model. Through conversations, seminars and papers I gained a better appreciation of the information processing assumptions of system dynamics that distinguish the subject from traditional micro-economics on the one hand and optimisation methods in management science on the other.

Modelling for Learning

After more than 10 years at MIT, I returned to England in 1986 to join London Business School. John Stopford made possible this return and I joined him in the School's Strategy department. From this new academic base I entered a productive and enjoyable phase of 'modelling for learning'. I was invited by Arie de Geus to collaborate with his Group Planning department in Royal Dutch/Shell, based at the headquarters of Shell International in London. There, over a period of six years, a series of modelling projects (some conducted by me, and others conducted by David Kreutzer and David Lane) unfolded within the framework of Arie's 'planning as learning' initiative. The idea was to take a fresh view of planning and decision making in organisations and see them as collective learning processes. A vital empirical finding, from educational psychologists' studies of child learning, was that learning and doing often go hand-in-hand; children learn as they play. Arie de Geus made the logical step from child's play to decision making by play. It was a big step. But it was insightful if you took the idea seriously, as he and others in Group Planning did. Modelling and simulation fit naturally with this new approach to planning since models are in essence representations of reality (toys) and simulators allow role-playing with a modelled (and much simplified) reality.

An important consequence of my collaboration with Arie and Shell was the launch, at London Business School, of a week-long residential executive education programme called Systems Thinking and Strategic Modelling (STSM). The programme used learning-by-doing to engage executives with the core principles of feedback systems thinking and system dynamics modelling. Chapter 2 (Introduction to Feedback Systems Thinking) and Chapter 3 (Modelling Dynamic Systems) are derived from STSM. Moreover, the programme brought together, for a period of 10 years, a faculty team at London Business School that helped to develop system dynamics in many important ways and materially contributed to the content of this book. The team members were Arie de Geus, Erik Larsen, Ann van Ackere and Kim Warren and then later Shayne Gary. I enjoyed working with this special group of people and know that together we accomplished a great deal. Thanks to you all.

The shower models in Chapter 4 were sparked by Erik Larsen who felt, in the spirit of modelling for learning, that we shouldn't simply lecture STSM participants about the tricky balancing loop in a shower 'system'. Instead, we should build a simulator that would allow participants to see (or even experience) the resulting dynamics. So together we developed prototype simulators that became the basis for the World of Showers A and B models in Chapter 4. Alessandro Lomi and Ari Ginsberg later joined us to write a journal article based on these models, entitled 'The dynamics of resource sharing – a metaphorical model'. Two MBA students at London Business School, Thomas Furst and Derrick D'Souza, helped me to develop an early version of the gaming interface, and my wife Linda Morecroft worked on the user guide and interface enhancements for World of Showers.

There is an anecdote to accompany the shower project. After Erik Larsen and I had formulated the model's equations, we needed to supply parameters. Erik suggested that the 'desired temperature' of the shower should be set at 25°C. I asked him if that number was high enough. He said it didn't matter as the choice would make no difference to the resulting dynamics, which was what we wanted the model to demonstrate. He was right in principle, but in practice (as I discovered by taking a thermometer into my home shower) water at 25°C feels distinctly cool. Erik was not easily moved by this piece of empirical evidence and so, as an amusing compromise, we decided to locate the model's imaginary shower taker in a hot and humid climate where a cool shower would be both desirable and plausible.

Perhaps the most memorable project from the modelling for learning era was a study of the structure and long-term dynamics of global oil markets. This study, conducted with the help of Kees van der Heijden, led to the Oil Producers' model described in Chapter 8. At the time, Kees was head of Group Planning's renowned scenario development team. He brought together 10 Shell managers who contributed to the model's conceptualisation. The project was a good opportunity to engage these managers with the model building process and to build a model that captured a collective view of their oil world as the basis for subsequent scenario development. The original Oil Producers' model was developed in the iThink modelling language. But several years later, prompted by a suggestion from Erik Larsen, the model's equations were transported into Visual Basic and a dramatic new interface was overlaid as the basis for experimental work on decision making in dynamically complex environments (the global oil industry is certainly dynamically complex). This work was carried out by Paul Langley as part of his doctoral thesis at London Business School ('An experimental study of the impact of online cognitive feedback on performance and learning in an oil producer's microworld', November 1995).

Systems Thinking and Strategic Modelling ran twice a year for 15 years and brought system dynamics to hundreds of managers and senior staff from organisations around the world.

The Dynamics of Strategy

Around 1995, I began working with Kim Warren on the dynamics of strategy. This development was motivated by our shared interest in strategy (we were both in the Strategy department at the time) and also by our familiarity with a widely cited paper in the academic management literature entitled 'Asset stock accumulation and sustainability of competitive advantage'. The paper was written by INSEAD's Ingemar Dierickx and Karel Cool and appeared in *Management Science* in 1989. Their argument was that the sustainability of firms' competitive advantage could be better understood by thinking about the way firms accumulate the asset stocks or resources that underpin their business. A firm might achieve competitive advantage by building a distinctive set of asset stocks that rivals would find difficult to imitate. Sustainability of competitive advantage would stem in part from the time it takes to accumulate or reconfigure such assets or resources. We realised that here was a dynamic view of firm performance that could be further developed by formally linking system dynamics with the resource-based view of the firm (an important branch of contemporary strategy theory and practice).

Our way of carrying out this synthesis was to jointly design and launch an MBA elective course at London Business School, which we called the Dynamics of Strategy. Applied research projects followed, including PhD theses at London Business School by Edoardo Mollona, Shayne Gary, Abhijit Mandal and Martin Kunc.

Dynamic resource-based models of the firm were devised to study important strategy topics such as diversification and competitive advantage. The research partners for doctoral projects included François Delauzun from BBC World Service and Bill Howieson from Scottish Power. Another partnership was with the London Office of McKinsey & Co., during 1996–2000, when the Business Dynamics practice was in full swing. The company assembled a strong team of consultants with expertise in modelling, and they provided a sounding board for many fledgling ideas about system dynamics and strategy. My thanks to Andrew Doman who led the Business Dynamics initiative in London and to Maurice Glucksman, Paul Langley, Norman Marshall, Panos Ninios and Hendrick Sabert who collaborated with London Business School on a variety of projects and publications.

There are samples of this strategy dynamics work on the Learners' website and in the book. See in particular the materials on People Express Airlines in the learning support folder for Chapter 6 and the materials on diversification dynamics and metamorphosis in the v-Lecture folders. Also, Chapter 10 includes edited extracts from Martin Kunc's dissertation about product growth dynamics and industry competition in fast moving consumer goods. Kim Warren went on to further develop the SD-RBV theme in his Forrester Award-winning book, *Competitive Strategy Dynamics*.

Soft Systems and Complementary Modelling Methods

In November 2001, I was invited by Mike Pidd of Lancaster University Management School to join the INCISM network, and it was here, in a series of meetings that spanned two years, that I learned much more about soft systems than I had previously known. INCISM is an abbreviation for Interdisciplinary Network on Complementarity in Systems Modelling and its meetings were funded by the UK's Engineering and Physical Sciences Research Council

(EPSRC). The network brought together a mix of academics and practitioners to explore the combined use of what have become known as 'hard' and 'soft' approaches to systems modelling. One result was a book entitled *Systems Modelling – Theory and Practice*. Through the network, the book and subsequent conversations with both Peter Checkland and Mike Pidd, I have come to better understand where system dynamics fits on the hard–soft model spectrum. It seems to me that the juxtaposition of system dynamics and soft systems methodology (SSM) reveals, in tangible terms, quite a lot about the abstract philosophy of modelling – by which I mean the different ways in which modellers interpret situations in business and society. I touch on this topic in Chapter 2 (under 'event-oriented thinking'), in Chapter 5 (under 'modelling for learning and soft systems') and again in Chapter 10 (under 'mental models, transitional objects and formal models'). INCISM also inspired a plenary session on soft systems and modelling at the 2004 International Conference of the System Dynamics Society in Oxford. Presentations by Mike Pidd and Peter Checkland described the territory covered by hard and soft modelling approaches and opened up discussion about the role of both qualitative and quantitative system dynamics. In the UK there is a long tradition of qualitative system dynamics which was started by Eric Wolstenholme and Geoff Coyle. The Oxford conference built on this tradition with its theme of collegiality as a social and scientific process to mediate between competing or complementary world views.

My interest in complementary modelling methods was further reinforced through collaboration with the Operational Research and Management Sciences group at Warwick Business School. There I found colleagues working at the interface of operational research and strategy. We had much in common. The use of complementary models and frameworks for strategic development became the focus of activity for an informal research group that included Robert Dyson, Maureen Meadows, Frances O'Brien, Abhijit Mandal and Alberto Franco (all from Warwick at the time), Jim Bryant (from Sheffield Hallam) and me.

At Warwick, I also found experts in discrete-event simulation (DES). We soon discovered a shared interest in simulation methods that transcended our differences. With Stewart Robinson, I conducted a mini-project that compared system dynamics and discrete-event models of fishery dynamics. We each built a small model of a fishery following the normal modelling conventions of our respective fields. Then we compared notes. The project led to many interesting conversations about modelling and simulation. Some of our thoughts and conclusions are reported in the appendix of Chapter 9 on alternative simulation approaches. Although both system dynamics and discrete-event simulation are commonly viewed as hard system modelling approaches, their comparison illustrates an interplay and clash of world-views worthy of a soft systems study. In a sense, this comparison was our mini-project as we built separate fishery models and then reflected how our professional backgrounds led us to interpret and represent the problem situation in fisheries. The fishery models also opened the door to the discrete-event simulation community, making possible further collaborative research with Ruth Davies, Sally Brailsford and others at the boundary of system dynamics and DES.

How to Use This Book

To get the most out of *Strategic Modelling and Business Dynamics* it is important to develop a good intuitive feel for 'dynamics' – how and why things change through time. Personal experience of simulated dynamics is a good way to learn. So the book comes with chapter-by-chapter learning support folders, which are available on the Learners' website (see the About the Website Resources section). Each folder contains models and gaming simulators that allow readers to run simulations for themselves and to reproduce the time charts and dynamics described in the text. The models come to life in a way that is impossible to re-create with words alone. It is easy for readers to spot opportunities for learning support. A spinning gyroscope is printed in the page margin alongside text that explains how to run the simulator.[5] Examples include unintended drug-related crime, the collapse of fisheries, perverse hotel showers, persistent manufacturing cycles, boom and bust in new products and services, promising market growth, unfulfilled market growth, competitive dynamics, hospital performance and price volatility in global oil.

There are also PowerPoint slides with notes to accompany the book. They are available on the Instructors' website (see the About the Website Resources section). The slides include lectures and workshops which are organised chapter-by-chapter. They can be supplemented with assignments which are also to be found on the Instructors' website.

There are many ways to use the book, models and slides in university and management education, some of which are outlined below. No doubt instructors will adapt and tailor the materials to suit their own needs, but the following comments may trigger some useful thoughts.

MBA and Modular/Executive MBA

The book is derived from an MBA elective of the same name (Strategic Modelling and Business Dynamics SMBD) that I ran at London Business

[5] A spinning gyroscope is 'dynamically complex' and is therefore a good visual metaphor to signal the simulation of dynamics in business and society. A gyroscope behaves in surprising ways. For example, when prodded on its top-most point it moves at right angles to the direction of the push; a counter-intuitive response. A gyroscope is also self-balancing. It stands on a pointed-end, like an upright pencil. Yet instead of falling over, as might be expected, it appears to defy gravity by remaining upright with its axis horizontal; again a counter-intuitive response.

School for many years.[6] It therefore has a track record in graduate management education. To run a similar elective course at another business school I recommend starting with the well-known 'Beer Distribution Game' in the opening session and then working through a selection of book chapters complemented with workshops and assignments based on the learning support models. The Beer Game is a role-playing exercise for teams of students that examines supply-chain dynamics and coordination problems in a multi-stage production-distribution chain comprising retailers, wholesalers, distributors and a factory. The game can be purchased at modest cost from the System Dynamics Society *www.systemdynamics.org* and is a vivid way to introduce students to modelling, representation, simulation and puzzling dynamics. On this foundation can be built lectures and workshops that introduce feedback systems thinking and modelling (Chapters 2 and 3); examine the cyclical dynamics of balancing loops (Chapters 4 and 5); and overlay the growth dynamics of reinforcing loops to study limits to growth, stagnation and decline (Chapters 6 and 7). By the end of Chapter 7 students have covered the key concepts required to conceptualise, formulate, test and interpret system dynamics models. Then instructors can select among the applications presented in Chapters 8, 9, and 10 (complemented with system dynamics materials from other sources) to create a complete course with 30 or more contact hours offered in modular or weekly format. The material is best spread out across an academic term or semester to allow adequate time for reading, preparation and model-based assignments.

A full-semester twenty-eight session course suitable for graduate students can be found on the Instructors' website in the folder entitled Course Outlines. A fourteen session taster course specially designed for PhDs can also be found in the same website folder.

Non-Degree Executive Education

Materials from the book have also been successfully used in a popular one-week residential Executive Education programme called *Systems Thinking and Strategic Modelling* (STSM) which ran at London Business School throughout the 1990s. The purpose of this programme was rather different than a typical MBA course in strategic modelling and business dynamics. Participants were often senior managers and/or their experienced staff advisers. For these people it was important to communicate how they should *use* modelling and simulation for strategic development and organisational

[6]Over the years Strategic Modelling has also been taught by Ann van Ackere, Shayne Gary and Scott Rockart, who each brought their own interpretations to the core materials. My thanks to them for the innovations and refinements they introduced.

change. Mastering the skills to build models and simulators was secondary to their need for becoming informed model users, by which I mean people capable of initiating and leading strategic modelling projects in their own organisations – as many STSM participants subsequently did. So the programme was designed to emphasise the conceptual steps of model building including problem articulation and causal loop diagramming. The course also provided syndicate teams with a complete, compact and self-contained experience of the steps of a group modelling project from problem definition, to model formulation, testing and simulation. This compact experience was delivered through mini-projects, chosen by the teams themselves, and developed into small-scale models under faculty supervision.

The programme began in the same way as the MBA course, with the Beer Distribution game used as an icebreaker and an entertaining introduction to feedback systems thinking, dynamics and simulation. Participants then learned, through lectures and syndicate exercises, the core mapping and modelling concepts in Chapters 2 and 3. It may seem surprising that executives would take an interest in hotel showers and drug-related crime (the examples in Chapters 2 and 3 that illustrate causal loop diagrams, feedback structure, equation formulation and simulation), but they always did. Real-world applications were then demonstrated with lectures about serious and successful modelling projects such as the Oil Producers' model in Chapter 8 or the Soap Industry simulator in Chapter 10. In addition guest speakers from business or the public sector, sometimes past-participants of STSM, were invited to talk about their experiences with modelling. Participants also spent half a day or more using a strategy simulator such as the People Express Management Flight simulator (referred to in Chapter 6) or the Beefeater Restaurants Microworld, available from *www.strategydynamics.com*. Working in small teams of three or four, participants discuss and agree a collective strategy for their assigned company and then implement the strategy in the corresponding simulator. Invariably, when dealing with dynamically complex situations, the best laid plans go astray and teams' experiences provide much valuable material for a debriefing on the pitfalls of strategy making. The final two days of the programme are spent on the team mini-projects mentioned above.

Ten and twelve session taster courses suitable for MBAs and Executives can be found on the Instructors' website in the folder entitled Course Outlines.

Undergraduate and Specialist

Masters Courses

I am confident that the content of this book works for MBA and Executive Education. It has also proven to be suitable for undergraduate and specialist masters courses in modelling and simulation. Obviously undergraduates lack the business experience of typical MBAs. They will therefore find it harder to make sense of the coordination problems that routinely crop up in organisations and contribute to puzzling dynamics, chronic underperformance and failures of strategy. Here the book's website models perform a vital function. They bridge the experience gap by enabling younger readers to simulate puzzling dynamics and to experience coordination problems for themselves.

Otherwise the sequencing of materials can be much the same as for an MBA course, with perhaps more emphasis given to non-business examples and cases. For example, it is possible to devote an opening session to the fisheries gaming simulator in Chapter 1 as a replacement for the Beer Distribution Game. Alternatively in order to retain, at the start of the course, a vivid role-playing exercise and social 'icebreaker' then simply replace the Beer Game with the Fish Banks simulator. Like the Beer Game, Fish Banks is also available at modest cost from the System Dynamics Society *www.systemdynamics.org*. The game debrief can be supplemented with the model and materials in Chapter 1. Then after the game, instructors can cover the core modelling Chapters 2 through 5 and selectively add content from Chapters 6 through 10 to suit the audience. For example students who are not especially interested in firm-level business dynamics and strategy may prefer to spend more time on public sector applications in Chapter 9 and on the industry-level simulator of the global oil producers in Chapter 8.

A ten session taster course for Masters in Management students and for undergraduates can be found on the Instructors' website in the folder entitled Course Outlines.

Chapter 1

The Appeal and Power of Strategic Modelling

- Introduction
- A New Approach to Modelling
- The Puzzling Dynamics of International Fisheries
- Model of a Natural Fishery
- Operating a Simple Harvested Fishery
- Preview of the Book and Topics Covered
- Appendix – Archive Materials from *World Dynamics*

Introduction[1]

I have always been fascinated by models and games and particularly by model conceptualisation, the process by which people represent and simplify situations from the real world to make sense of them. Consider for example, the popular board game of Monopoly. Players find themselves as property developers in an imaginary city. It could be London or New York, except of course (and this is the curious thing) the board doesn't look remotely like a real city or even like a geographical map of either city. The game board is just a large square of card on which are printed neatly labelled and coloured boxes displaying familiar place names like cheap and cheerful Old Kent Road in brown, bustling Trafalgar Square in red and elegant Mayfair in dark blue. There are houses and hotels, but no streets. There are stations, but no railway lines. There is a community chest, but no community of people. There is a jail, but no police department. Players move around the city with a throw of the dice in a curious assortment of vehicles: a boot, a ship, a horse, an iron, a cannon and even a top hat. It is a fantasy world, a much simplified view of

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[1]The introduction contains edited extracts from my 2000 paper, 'Creativity and Convergence in Scenario Modelling'.

real estate in a city, and yet it captures something real – the essence of commercial property ownership and development in a growing competitive market. The more property you own and control, the more you earn. Bigger is better, winner takes all.

The challenge of any kind of modelling lies precisely in deciding, among myriad factors, what to include and what to leave out. The same principle applies whether you are devising a board game like Monopoly or building a simulator for a management team in BMW, Dow Chemical, Goldman Sachs, Harley-Davidson, Mars Inc., Microsoft, Royal Dutch/Shell or Transport for London. The starting point is essentially, 'what's important here?' What do you and others have in mind when you think about the strategy and future success of a business, a city or an entire industry? What is the issue under investigation and which factors need most attention to address the issue? These practical questions in turn raise a more basic philosophical question about how we conceptualise the enterprises in which we live and work. How do people, whether they are leaders, advisers or commentators, make sense of firms, industries or societies, explain them to others, and anticipate outcomes well enough to shape and communicate intelligent strategy and policy?

I can recall this fascination with conceptualisation from a time when business dynamics, or more generally system dynamics (and its specialist visual language of stocks, flows and information feedback), was entirely new and unfamiliar to me. It was back in the early 1970s. The *Limits to Growth* study, a research project exploring how to create an economically and ecologically sustainable society, was attracting attention worldwide. The project was conducted at the Massachusetts Institute of Technology (MIT) and two influential books based on this work, *World Dynamics* (Forrester, 1971) and *Limits to Growth* (Meadows *et al*., 1972), had already been published. Further work on the paradox of global growth and sustainability was in full flow. Thousands of miles away I was a graduate student at London University's Imperial College, completing a masters degree in operational research. I had only just encountered *Industrial Dynamics*, the seminal book that marked the beginning of system dynamics (Forrester, 1961).

Nevertheless, I experienced a sense of excitement about the possibility of using computer models to visualise and simulate issues that were foremost in the minds of business and political leaders and important for our everyday lives. Certainly I was no novice to computer modelling, but up until then I had used computational power for optimisation and decision support. What I found appealing in this new area of system dynamics was the promise of a subject aimed at broad policy making backed up by the discipline of model building and the power of simulation.

Imagine you are contemplating the dilemma of fast-growing global population in a world of finite resources. Today, there are 7 billion of us on the planet. Back in 1850 there were just over one billion. By 2050 there could be as many as nine billion people. Is it really possible that mankind could outgrow the planet and overexploit its abundant natural resources to usher in a dark age of pollution, poverty and suffering? Why might this happen and when? How do you begin to answer such questions and how do you conceive a 'global system' in your mind? I was captivated by a representation in *World Dynamics* that limited itself to only two pages of symbols whose clearly defined purpose was to explore alternative future time paths for global industrial society. It was a bold sketch on a compact canvas.

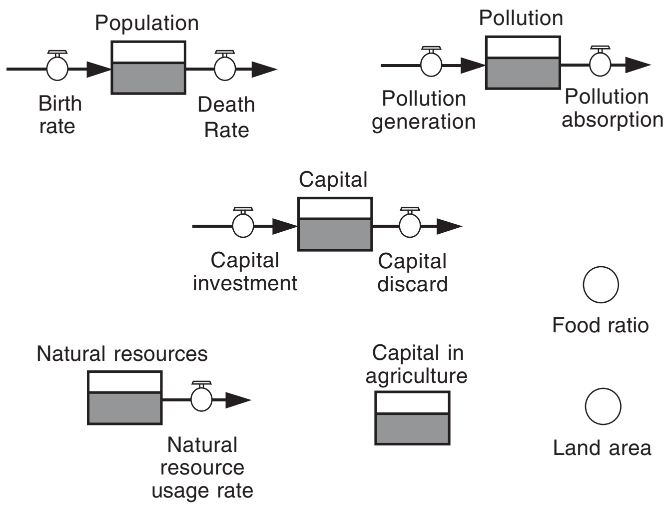

Figure 1.1 Stock accumulations for global growth
Source: Adapted from Forrester (1971, pp. 20–21).

For those who have read *World Dynamics*, Figure 1.1 will evoke memories of the model. However, for most readers who are new to system dynamics you will glimpse what I saw as a graduate student: strange symbols and familiar phrases which claim to set some sort of boundary on the set of factors that will shape the environmental and economic destiny of mankind. I have deliberately chosen to show a much-simplified diagram that leaves out many intermediate variables and the complex network of connections, because that is how I first perceived the model. There are only four stock accumulations (shown as rectangles with inflows and outflows), representing aspects of our world, that have grown steadily and relentlessly over many centuries: population, capital, pollution and natural resources (which have declined). This fact alone I found remarkable for its brevity yet common-sense appeal. To understand global limits to growth one surely has to think hard about the drivers of population (birth rate and death rate, shown as small circles with tiny taps superimposed on arrows); the engines of human economic activity (capital investment, capital discard and the usage rate of natural resources); and the consequences of human activity on the global environment (the processes of pollution generation and absorption).

These factors must co-evolve over time. But what forces or influences make sure they evolve in a balanced way that can satisfy the aspirations and sustain the living standards of a healthy global population? My picture does not show the full web of coordinating forces. That is something you will learn to model and interpret later in the book. For now you just have to imagine there is such a web operating behind the scenes that determines how, for example, the birth rate depends on population, capital and pollution, or how capital investment depends on population and natural resources. But can a sustainable balance be achieved? Is there a coordinating web that will steer global growth within the constraints of finite natural resources, limited land area, and biological/physical laws (that govern the world's ecology), while at the same time meeting the needs of billions of global stakeholders (parents and families, investors in productive capital, exploiters of natural resources)?

It came as a shock all those years ago to realise there is no nation, no government and no responsible business community that has the power or the information to mastermind a global growth engine.[2] A coordinating web is certainly there (reproduced in the Appendix as Figure 1.13), but it is a weak and imperfect invisible hand. In the long run, this invisible hand will achieve a ruthless balance of population, resources and human activity. But the time path to this ultimate balance may involve a catastrophic decline of living standards and population or spiralling pollution.

Figure 1.2 compares two (among many) alternative time paths that summarise the message as I recall it from my early encounter with system dynamics (Randers, 1980). Bear in mind these are rough hand-drawn sketches, not formal simulations. Nevertheless, the century-long timescale on these charts is representative of the time horizon in the original study and left a deep impression about the ambition of the field to understand the long term by simulating the interaction of human decisions-and-actions with enduring natural forces. On the left is a likely scenario. Global carrying capacity (defined as how much human activity the globe can sustain) starts high in the uncrowded world of the 1950s. Human activity starts low. As population and capital grow, human activity rises steadily and exponentially, approaching the

[2]The same idea of limited ability to control situations applies to firms in competitive industries and, to some extent, to business units and functional areas inside corporations and firms. Management teams can devise strategy (the intended strategy), but a whole organisation stands between their ideas and resulting action, so the implemented strategy is often different than intended. The levers of power are only loosely connected to operations.

finite (but unknown) global capacity around the turn of the millennium. There is no particularly strong signal to announce that this hidden capacity limit has been reached, nor any coalition of stakeholders with the power to restrict human activity once the limit is exceeded. So 'the band plays on' for another 20 years. Collectively, we live beyond the generous but limited means of our planet. This overexploitation of resources and the environment leads to a steady erosion of global carrying capacity and a consequent rapid decline in human activity. In human terms, this multi-decade period of decline is a dark age of low living standards, high pollution, food shortage, premature death and economic depression. It is a dramatic story arising from simple yet plausible assumptions about human behaviour and planetary limits.

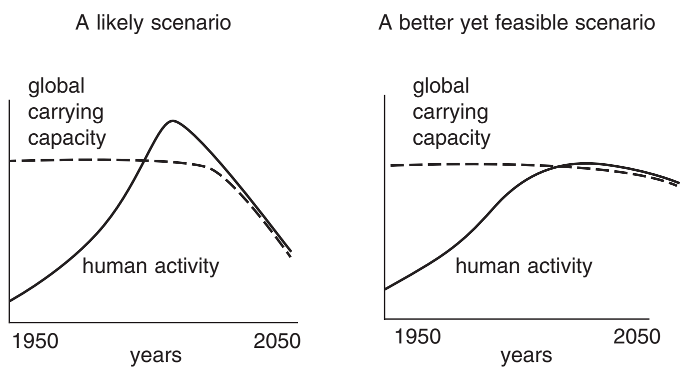

Figure 1.2 Limits to global growth – rough sketches of alternative futures

The story has not really changed in the four decades since it was first simulated. But there was always another, much more optimistic story. This alternative and sustainable future is sketched on the right of Figure 1.2. I won't say here what differences in the coordinating web can lead to this new outcome. Instead, I invite you to think about the task of balancing the stock accumulations in Figure 1.1 in light of what you learn from the book. I also refer you to the comprehensive simulations of the *Limits to Growth* team (Meadows *et al.*, 1972; 2002 and Cerasuolo, 2013) and to two of the original simulations from *World Dynamics* reproduced in the Appendix as Figure 1.14.

A New Approach to Modelling

World Dynamics and *Limits to Growth* anticipated a new and participative approach to modelling and simulation. People's ability to manage their complex world can be improved by visualising and simulating it. Plans and alternative futures become clearer by rehearsing them (O'Brien and Dyson, 2007). Only now is this approach coming to be widely appreciated in business, political and academic circles. During the 1970s, models were still viewed as instruments for accurate prediction whose validity rested primarily on short-term predictive power, conformance with established economic theory and goodness-of-fit to historical data. Modelling for learning, of the kind presented in this book and intended to complement people's mental models, was in its infancy.

The idea of rehearsing alternative futures is fundamental to contemporary strategic modelling and scenario development. The purpose of models and simulations is to prepare organisations and individuals for alternative futures by bringing these futures to life so they are imagined more vividly than would otherwise be possible. Moreover, as you will see throughout the book, strategic models not only help people to generate alternative futures for their firms and industries, but also to challenge, shape, change and enrich their interpretation of a complex world.

An important objective for modellers (and arguably for anyone in a leadership position who has to make sense of complex business or social situations, devise strategies and communicate them) is to find a compact 'shareable' description of how a firm, industry or social system operates. Sooner or later, the creative and divergent thoughts that are present at a very early stage of enquiry (captured in the phrase 'there's a lot going on out there') must be turned to convergent thoughts that focus group attention on the essence of the situation at hand (by agreeing, through ruthless pruning, what's really important and what can be safely ignored). In business dynamics, this creative process of simplification (known as 'conceptualisation') takes shape as a picture of a firm or industry that the modeller agrees with the project team. There are of course guidelines to follow. You begin by identifying so called stock accumulations and feedback loops, the visual building blocks of system dynamics models and simulators. Striking the right balance of creativity and convergence is an essential art of modelling. The parsimonious structure of the *World Dynamics* model is evidence of creativity and disciplined convergence in model conceptualisation. The model's enduring appeal and power to communicate lies partly in its concise yet compelling representation of a massively complex reality.[3]

[3]Modelling can be controversial. *World Dynamics* was and still is a thought-provoking model, a potent catalyst for political debate and an instrument for serious policy making. It was also a focus of learned criticism about the nature and use of modelling and simulation in the social sciences. Quotations from the press and academic literature at the time convey the impact, both positive and negative, of the model on opinion leaders: 'This is likely to be one of the most important documents of our age …', *New York Times*; 'There are too many assumptions that are not founded, and there is too high a level of aggregation in the model', *Science*; 'This year will not see the publication of a more important book than Forrester's *World Dynamics*, or a book more certain to arouse dislike', *Fortune*; 'This is a piece of irresponsible nonsense, a publicity stunt … extremely simplistic, given the

The Puzzling Dynamics of International Fisheries

By now I hope your curiosity about modelling is stirred, but before probing the basic concepts and tools used by system dynamics modellers, I want to show you a model, a small model, designed to address an important contemporary issue facing society. I will explain its main assumptions, demonstrate some simulations and then give you the opportunity to run the simulator for yourself.

The topic is fisheries. The problems of overexploitation facing international fisheries are well known, widely reported in the press and a subject of government policy in many nations. The performance of international fisheries is indeed puzzling. Fish naturally regenerate. They are a renewable resource, in apparently endless supply, providing valuable and healthy food for billions of consumers and a livelihood for hundreds of thousands of fishing communities worldwide. The fishing industry has been in existence since the dawn of civilisation and should last forever. Yet fish stocks around the world are volatile and some are even collapsing. Once rich fishing grounds such as Canada's Grand Banks now yield no catch at all. Stocks in other areas, such as the English Channel, the North Sea and the Baltic, are in terminal decline.

The issue is powerfully expressed by environmental journalist Charles Clover (2004) in his acclaimed book *The End of the Line*. Here is an excerpt from Chapter 1:

> Fish were once seen as renewable resources, creatures that would replenish their stocks forever for our benefit. But around the world there is evidence that numerous types of fish, such as the northern cod, North Sea mackerel, the marbled rock cod of Antarctica and, to a great extent, the west Atlantic bluefin tuna, have been fished out, like the great whales before them, and are not recovering … The perception-changing moment for the oceans has arrived. It comes from the realisation that in a single human lifetime we have inflicted a crisis on the oceans greater than any yet caused by pollution. That crisis compares with the destruction of the mammoths, bison and whales, the rape of rainforests and the pursuit of bushmeat. It is caused by overfishing.
>
> (from *The End of the Line* by Charles Clover, published by Ebury. Reprinted by permission of The Random House Group Ltd and Charles Clover.)

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current state of knowledge in the social sciences', economists from Yale. Notice the sharp division of opinion on the scope, size, adequacy and usefulness of the model. The serious press thinks the work is important for its readers and worthy of policymakers' attention. Academics question the model's apparent simplicity. Not surprisingly judgements vary about the complexity and accuracy required of models (or even ideas and theories) for them to offer useful guidance to business and society. Modellers need to strike a careful balance.

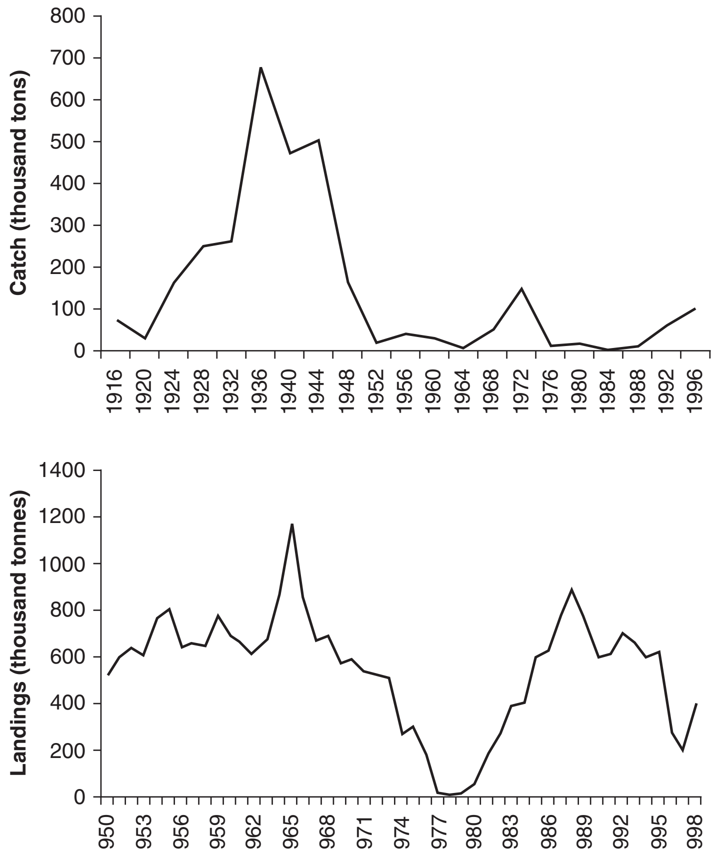

Figure 1.3 Pacific sardine catch (top) and North Sea herring catch (bottom) from Fish Banks debriefing materials (Meadows *et al.*, 2001)
Source: Nichols (1999).

Figure 1.3 shows evidence of overfishing from two real fisheries. This kind of time series data is a useful focus for model building because it contains the dynamics of interest. The top chart shows the Pacific sardine catch in thousands of tonnes per year over the period 1916–1996. The annual catch grew remarkably between 1920 and 1940, starting at around 50 thousand tonnes per year and peaking at 700 thousand tonnes per year – a 14-fold increase. Over the next four years to 1944, the catch fell to 500 thousand tonnes per year, stabilised for a few years and then collapsed dramatically to almost zero in 1952. Since then it has never properly recovered. The bottom chart shows a similar story for the North Sea herring catch in the period 1950 to 1998. However, in this case, following a collapse between 1974 and 1979, the fishery did recover in the 1980s and early 1990s with an average annual catch around 600 thousand tonnes per year – similar to the catch in the 1950s and 1960s.

Why does overfishing happen? We can be sure that no fishermen set out with the deliberate intention of depleting fisheries and wrecking their own livelihoods. Yet this outcome has been repeated in fishing communities around the world.[4] A good explanation is to be found in a fisheries gaming simulator called Fish Banks, Ltd (Meadows *et al.*, 2001; Meadows and Sterman, 2011). Since I am not an expert on fisheries, I will base my model on this popular simulator. Fish Banks has been used to teach principles of sustainable development to audiences that include politicians, business leaders and government policy advisers as well as fishing communities and high school students. Incidentally, it is no coincidence that the lead designer and author of Fish Banks, Dennis Meadows, was also a principal investigator in the *Limits to Growth* study. Fish Banks has proven to be a potent metaphor for sustainable development in many industries and enterprises, including the world itself viewed as a huge socio-economic enterprise.

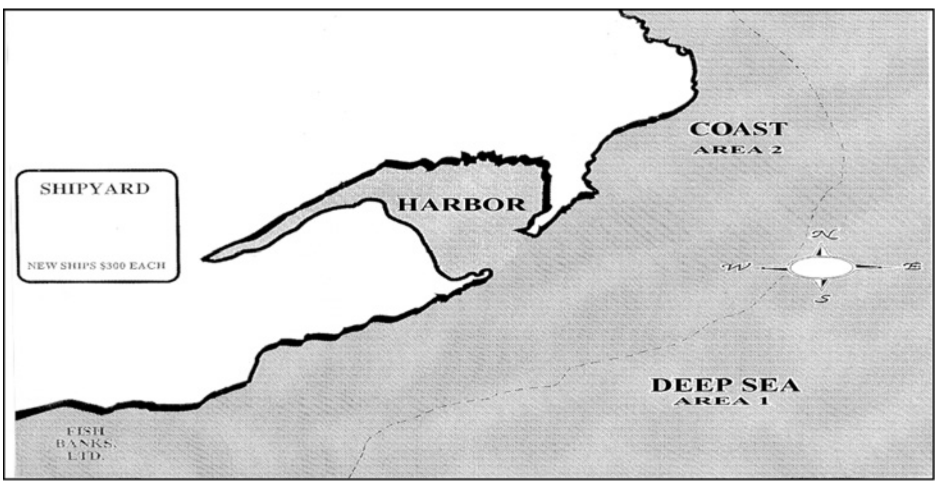

Figure 1.4 An imaginary fishery – the game board of the original FishBanks, Ltd
Source: Meadows, *et al.*, 2001

Figure 1.4 shows the Fish Banks game board and its imaginary fishery. There is a region of ocean, close to land, containing a single species of fish. Fish regenerate as a function of the existing population. The local fishing community buys ships from the shipyard and takes them to sea to harvest fish. The total catch depends on the number of ships, the fish population and other factors, such as the weather. In the game, as in real life, the fish population is not known accurately, although it can be estimated. Also, in the game, as in

[4]Clover describes the poignant scene at Lowestoft in recent years: the unrepaired doorways and shabby 1930s office buildings on the seafront, symbols of economic collapse. This town was once among England's greatest fishing ports, famous the world over, with a history spanning 600 years.