RESOURCES, FINANCIAL RISK AND THE DYNAMICS OF GROWTH

SYSTEMS AND GLOBAL SOCIETY

Roberto Pasqualino and Aled Wynne Jones

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ROUTLEDGE

"As the impact of climate change progresses, relatively likely and foreseeable events, such as production shocks in the food systems as a result of disease, weather-related yield loss, infrastructure failures due to physical or digital issues, need to be better modelled and understood. This new understanding of risk, as a dynamic topography where sub-acute and acute trends and events may come together rapidly and at large scales requires new analytical foundations. The model, ERRE, presented in this book offers the foundation to simulate and query how these shocks may occur, and may cascade through the global social and financial systems. These insights are key to building the physical, community, and financial resilience that must be at the heart of humanity's efforts in the 21st century."

Molly Jahn, *Professor at University of Wisconsin-Madison, USA*

"Nearly 50 years have passed since the publication of the first world model, the famous report to the Club of Rome titled 'The Limits to Growth.' Today, we see a remarkable return of interest in this subject and one result is this book by Pasqualino and Jones that extensively reviews the earlier work and includes the description of an improved world model called ERRE. We badly need formal models to understand a world that's becoming way too complex for our intuition to grasp. This book is a considerable step forward in the right direction."

Ugo Bardi, *Professor at University of Florence, Italy*

"Roberto Pasqualino and Aled Jones have produced a hugely ambitious and timely piece of work. In its time, the original 'Limits to Growth' was hugely influential, and as we lurch towards a climate emergency, this thoughtful and thorough approach to modelling the world deserves to have as much impact, not least in its challenge to the dominant reductive economic thought."

Nick Silver, *Chairman, Climate Bonds Initiative, UK*

"The Anthropocene demands a fresh approach to analysing the real risks to humanity of a destabilising Earth System. This book is a big step towards meeting that challenge, exploring the shocks, feedbacks, tipping points and other disruptive surprises that might lie ahead."

Will Steffen, *Emeritus Professor at the Australian National University, Australia*

"The importance of modelling is not being right, it's about helping us think more correctly. The Club of Rome's 1970s modelling, revisited in this book, was meant to explore highly uncertain long term futures to help us think more correctly about ecological limits. This book continues that tradition, along the way exploring the limits of modelling as well as the benefits of non-linear dynamics in understanding the dramatic environmental choices facing us."

Michael Mainelli, *Executive Chairman, Z/Yen Group*


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Resources, Financial Risk and the Dynamics of Growth

This book presents a new system dynamics model (the ERRE model), a novel stock and flow consistent global impact assessment model designed by the authors to address the financial risks emerging from the interaction between economic growth and environmental limits under the presence of shocks.

Building on the World3–03 Limits to Growth model, the ERRE links the financial system with the energy, agriculture, and climate systems through the real economy, by means of feedback loops, time lags and non-linear rationally bounded decision making. Prices and their interaction with growth, inflation, and interest rates are assumed to be the main driver of economic failure while reaching planetary limits. The model allows for the stress-testing of fat-tail extreme risk scenarios, such as climate shocks, energy transition, monetary policies, and carbon taxes. Risks are addressed via scenario analyses, compared to real available data, and assessed in terms of the economic theory that lies behind. The book outlines the case for a government-led system change within this decade, where the market alone cannot lead to sustainable prosperity.

This book will be of great interest to scholars of climate change; behavioural, ecological, and evolutionary economics; green finance; and sustainable development.

Roberto Pasqualino is Visiting Researcher of the Global Sustainability Institute at Anglia Ruskin University, UK. Roberto's research interest is in feedback modelling of industrial policies for the analysis of financial risk and sustainability. This involves the nexus between food security, energy transition, and those environmental and economic shocks that have the potential to disrupt systems in a complex world.

Aled Wynne Jones is the inaugural Director of the Global Sustainability Institute (GSI) at Anglia Ruskin University, UK.


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Resources, Financial Risk and the Dynamics of Growth

Systems and Global Society

Roberto Pasqualino and Aled Wynne Jones

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To Elisabetta
Among those who change the world for the better
To Vaughan and Lewis
Parts of society's next generation


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Thank you all. Let's go save the world.

Foreword

Fifty years ago I fortunately chose to attend a physics colloquium at MIT and met a small team of researchers under the leadership of Jay W. Forrester. Two years later, as part of this team, we published *The Limits to Growth*. This study for the Club of Rome changed the world, by raising awareness about the physical limitations of planet Earth.

Economics, most other academic disciplines, and most governments up until that point did not consider nature, and – more specifically – the world's natural resources, as an integral part of the human enterprise. The world was still seen as very big, with little impact on the dynamics of society. *The Limits to Growth* sought to explore, and showed, that conventional economic growth would tend to expand the human ecological footprint so rapidly that it would overshoot the ability of the planet to supply the resources needed or overload land and oceans with pollution that would reduce their ability to keep up with human demands. In overshoot, society either collapses or organises managed decline. Today – some 50 years after *Limits* – the world finds itself in overshoot and tending to ignore this fact.

With my many colleagues around the world, I have spent the years since the publication of *Limits* advocating for humanity to live in sustainable harmony with the rest of nature.

That is not to say that the future is totally broken. It is to say that human society needs to actively think about these challenges and ensure governance systems that manage them rather than just hoping a solution will land from somewhere at some point. While there have been huge improvements in how industry works – we no longer have black soot billowing out of industrial chimneys in the middle of New York – there is still a long way to go.

And there are signs of progress in other areas. In this book – for example – we see a new global model that can explore a different set of scenarios to those presented in *Limits*. In my book *2052* I presented a forecast for global developments towards the middle of this century. It is a slightly more optimistic educated guess than the darkest scenarios of *Limits*. The risks are all still there, but some of the trends are bending in the right direction. In this book some of those risks are explored through a new model and a new set of scenarios – and with a time horizon all the way to the end of this century. Importantly, it explores the approach to

those limits and risks and helps us understand how society might respond, either proactively or reactively.

I am optimistic a better world can be created. However, we need to actually plan that better world. If we don't actively manage the risks we will see shocks in our economic and financial system. Some of these shocks might be large enough to create a paradigm shift in human history.

Finally, it is important to stress that these models do not forecast the future. They test different possible outcomes based on a set of assumptions and the likely impact of a set of policies or processes that govern society. The idea is that these scenarios can then inform society on how to change those policies and processes to avoid some of the worst outcomes.

How did *The Limits to Growth* change the world? It opened up space for discussing these challenges. It created an argument for setting up international governmental processes to manage environmental challenges. It inspired, and continues to inspire, generations of sustainability champions. But more importantly it annoyed a lot of people.

So, as I did in *2052* I offer a final word of encouragement – in particular to the younger of the authors as he sets out on his journey into this world of modelling and advocacy. Hope for the unlikely! Work for the unlikely! And be bold.

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Preface

Models and decisions

You can think of the world as an imaginary box. The simple action of associating a non-existent box with the world within the mind might be considered of little use to the scientific community or policy makers. However, such an action represents the beginning of a journey to understanding global systems through the creation of a mental model of the entire world.

By definition, a model is a simplified, reductionist representation of reality. Our mind cannot give attention to everything surrounding us. A model can capture some particular details of the observed environment allowing people to interact with it. These representations are models of the reality in the mind, or better, mental models.

For example, let us say that one child would like to move a box full of toys from a position A to B. The box is heavy enough that the child cannot lift it up, but light enough they can drag it on the ground. They would not need to know every single detail of the toy box to achieve their desire of moving the box. Details such as the exact number of toys in the box, their colours, who manufactured them, would not help in dealing with the issue they are facing. Intuitively, the child would make a calculation of the relative mass and volume of themselves and the ones of the box. By simply touching and approaching the box physically, they would make some tests to adjust the initial calculations to the ones necessary to perform the action correctly. Then, they would push (or pull) the box from A to B. The child created a mental representation of themselves interacting with the box and the ground in relation to the purpose of the action. They gave some attributes to every participant (nothing detailed), applied some testing thus improving the initial mental model, used such a model to decide what to do and how to do it, and performed the action. The mental model was in the mind of the child for the full duration the action was taken. Once the action was completed, the mental model vanished, dragging the child's attention to something different (for example the toys in the box).

Mental models are a part of being human. They can be created, evolve, and get discarded at the speed of thought without even realising we are using them. The main purpose of a mental model is supporting us in taking decisions which

drive our actions that interfere with the dynamics of our environment. Whereas decisions can be taken without any support from mental models – i.e. the reason why the child wants to move the box can be completely irrational – we often face situations where the cost of failure can be prohibitive in comparison to what we believe is acceptable. Our feelings alone do not help much in turning such a situation towards the desired path.

Our world is a dynamic system and we are part of it. As individuals we keep evolving and interacting with the elements of the environment that surround us. The food we eat, the air we breathe, the people we socialise with are all elements of our environment and we are part of theirs. As groups we also keep evolving and interact with elements of world ecosystems as well as with other groups of people. As a society we organise ourselves in many different ways with the final aim of satisfying each other's needs both locally and internationally. We extract resources to produce goods and warm houses up, use land and its nutrients to produce the food we eat, use science to innovate our society towards a more desirable future, and so on.

Both as individuals and as a society we are part of wider systems. A 'system' can be defined as a set of interconnected elements (both living and non) that interact one to another over time towards a purpose. A mutual relationship (both direct and indirect) among two elements of a system is referred to as a 'feedback.' At the individual level, examples of feedback may include tasting food (direct feedback from food to our brain through our sense), or a teacher providing corrections to a student based on their homework. At the societal level, we can consider the population of a nation that votes for its preferred political representatives, or a government that goes into war (the feedback would be less direct here, for example involving first a lack of resources, then a persistent financial and economic crisis, and then a decision to engage into war with someone else). Feedbacks are our means for adaptation to our environment and the foundation for learning. Thus they form the basis for the experience we cumulate in our lifetime that drives the actions we take in particular situations.

Modelling is an activity we all do when facing a new situation that requires our attention and input. If we focus on a particular real system, there exist an infinite number of mental models that can help us understanding it. When we feel comfortable with a particular mental model of reality we take an action and interact with it. The reality, in most cases, feeds back to us in one way or another, showing if the mental model was mostly wrong (the feedback of the reality is something we were not expecting with potential negative consequences) or mostly right (somehow the consequences of our actions were expected and have a positive outcome). In the first case we would reject the model, and in the second we would accept it, aggregating it to previous ones to develop a deeper understanding of what we believe is surrounding us and how we can live with it. Because we mostly learn through feedback from the environment we can perceive, we are naturally forced to learn mostly from our past experiences, and have trouble in solving situations we have never faced before.

One of the most successful outcomes of our global society is the way we were able to accumulate and spread knowledge and information over space and time.

Nowadays our mental models are mostly formed through education, personal relationships, and as an outcome of the exposure to daily events and information from media, while filtered from the lens of the mental model that we currently own. When we face a new challenging situation we would normally look for advice among the people who know more than us about that specific problem. When people cannot be reached directly, information tends to be gathered through literature, consulting reports available within the extremely large amount of knowledge we have created and deposited, or, at last resort, interacting with the environment by mean of tests and experiments with tools. This is also the way we manage risk of failure, increasing our likelihood of success to reach the desired results within the available time. Still feedback from reality remains the key for learning, helping us to deal with similar situations in the future. It is worth noting that despite the individual modelling activity being carried out at a minimum level in relation to the problems we face, we are still all modellers who accept and reject information within our set of beliefs and mental architectures.

All models are questionable. As such they must be continuously tested in comparison to the reality they aim at representing, and should be effectively shared among communities to both influence their mental models (learning), and being influenced by those. Most important, because our environment is dynamic (it changes over time), it is fundamental to innovate models of the past because they might not be suitable for the problems of the present and the future. The most common ways to share and influence each other's mental models is through simple conversation and communication. Words, diagrams, pictures are all tools that can be used to rationalise concepts that can be shared and influence mental models of others as well as your own. They are useful ways to drag mental models out of the mind of people and welcome criticisms from others. In so doing it is possible to create a shared and agreed understanding of real-world systems among different communities, forming the basis for human institutions and a tiny certainty within our uncertain world.

Computer models are one of the ways to formalise the mental models in a format that is sharable among many. Computer models can also use calculation power to capture some characteristics of the reality that the mind finds difficult to catch. Characteristics of the reality that people can measure, interpret, or formulate hypothesis on, in relation to their possible evolution over time. Computer models can be seen as extensions of mental models, and can play an important role in structuring a better society. By using computer models to drag mental models out of people's mind, it is possible to create models built by the aggregation of the mental models of many, test and improve those over time, and use the models for pursuing some objective for the community.

The world and the society

Coming back to the box as a mental representation of the entire world, we might use it to start developing a computer model. As an empty box, the model is static (does not change over time) and does not capture any information about the

state and evolution of any system in the world. The practical use we can make of it is none. Higher success can be achieved by exploring what there is inside the box, some relations among such elements, and possibly their behaviour over time in particular conditions.

When opening the box, it is easy to list everything that comes into our mind that would be part of it. We can range from the atoms of hydrogen to entire oceans, from the consciousness of one person to the information captured in their DNA, from a tiny village in the countryside in Africa to the network of 214 nations defining the geopolitics of our planet. Some of these aspects can be approached with certainty, others would be less clear since they are not yet understood by humanity or not scientifically attainable. Some elements can be listed, but it would be not feasible to define how they interact with other elements of the whole.

Two simple ways to differentiate systems of the world can be on the basis of the time they take to evolve and their scale of impact. While some ecosystems on Earth take thousands to millions of years to exhibit significant changes (for example, the time to form crude oil and coal in the ground, the time for Earth to absorb carbon dioxide (CO_2), or the time for new forms of life to emerge), the time frame taken into account for people dealing with daily activities, businesses, and politics ranges from hours to a few decades. It takes less than two decades for a new born to be considered an adult; it takes a few years to receive an education and set up a career to have a role in society; it takes about two decades to spread technologies and products in society after they have been discovered for the first time; it takes about five years for a government to be responsible for managing nations in democratic societies; it takes months to a few years to substitute goods and appliances in your house; it takes generations to change culture in a society; it takes years to deal with conflicts and wars among nations; it takes days, or even hours to take decisions in the financial market to invest the next dollar profitably. But the leftovers of human passage on Earth can take hundreds to millions of years to be reabsorbed into the environment. Together as a dominant species on the planet we were able to become a planetary force strong enough to change the climate from the era of the Holocene (a period of relatively stable climate that started about 11,700 years ago) to the Anthropocene due to emissions generated from a massive economy founded on the paradigm of growth (this is considered to have started with the Industrial revolution in the 18th century).

Society itself can be thought of in many different ways as well. Culture, wealth, and religion are common ways to differentiate groups of people, one to another. From a global perspective, we can see the world divided in 214 countries covering different geographies and interacting one to another through the exchange of commodities and services (and people). It is also possible to see the world in terms of a financial district controlled by central banks, each with a different currency, sometimes involving multiple countries (see Europe). Seen both as countries and a financial district the main philosophy unifying all of those is the interconnection and the ability of some to solve the problems of others in a gigantic supply-demand network of global communities driven by production,

trade within global markets, and the overall tendency to expand towards the next challenge. Based on the assumption of increased well-being for all, reduction in inequality among rich and poor, eradication of food insecurity and poverty in the long term, and the assurance of maximum employment levels for all, more and more power has been given to the financial system which was designed to address the disequilibrium of the world society and move towards growth. In so doing, the paradigm of economic growth became the strongest force dominating human development since James Watt invented the steam engine.

Despite this approach, which allowed for the widespread deployment of new technologies and modified the socio-economic environment to the point of being unrecognisable from just a few decades ago, all production still relies on the extraction and depletion of some natural ecosystem. In particular every material good we use uses minerals, every house needs energy for lighting and heating, every business needs energy for operating machines, every farm needs water, land and fertilizers to produce food, and so on. Each of these processes has the peculiarity of generating waste and pollutants as well as depleting the natural resources at a pace that leaves less time before reaching the limits of the planet. Such an approach is unsustainable and actions should be taken collectively and urgently if we are to avoid the worst impacts.

Governments have an extremely important role in the sustainability challenge. Despite technological change, the process of decision making and policy development remains firmly based on a traditional humanistic approach. Although information is more easily available to decision makers in shorter time frames, and despite an increasing use of computerised algorithmic decision making, the final decision is based on the mental models of the decision makers informed through dialogue and feedback from the various elements of the society they aim at supporting. Based on the understanding and knowledge relative to the systems composed of businesses, citizens, and finance, it is clear that, in its current state, decision makers cannot effectively deal with important global trends which have the potential to negatively feedback on our society such as systemic crises, recessions, and conflicts. Such a global system needs to be reformed. A new mental model is needed.

Sustainability, resilience, and global models

Given a variety of systems in the world evolving with different time scales and affects, how can we define correctly the right granularity and content of a computer model? It is the purpose of the model that determines its content. For example, if we want to study the world from the angle of climate interaction with the oceans, the physical characteristics of a single person might not be relevant. The knowledge available to inform the model and the methodology adopted are also important constraints defining the format of the model and its capability to study some particular world dynamics. In turn its format and accessibility will determine whether it influences the mental models of decisions makers.

The models that are presented in this book look at the problems of sustainability, systemic risk, and resilience based on current behaviour of human society

dealing with the resources of the finite planet in the context of major shocks. One of the earlier definitions of sustainable development was provided by the Bruntland report in 1987 as: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Such a definition remains hard to interpret by policy makers and businesses when they make decisions, and unfortunately, the long term in the year 1987 has become the short term in the year 2020. In fact, the concept of resilience, the ability of an ecological system to absorb and react to perturbations and return to its normal state, became fundamental for a transition towards a more sustainable world.

Sustainability and resilience must be seen as multidisciplinary challenges involving different systems interconnected through mutual feedbacks. A system characterised by the presence of closed loop feedbacks takes the name of 'complex system,' indicating that the evolution of every component should not be considered in isolation but as outcome of its interactions with the other components. In the case of global scale models, we can consider those as 'complex macro-systems' involving knowledge coming from social, biological, political, environmental, and economic perspectives among others.

In Part I of this book, we explore a revisit of the Limits to Growth model, presented in its last version (Meadows et al. 2003). As the analysis focuses on sustainability, the model is relatively small, with a focus on the dynamics of real output and population growth in a finite planet between the years 1900 and 2100 (Chapter 1). A comparison of world limits with current global trends (Chapter 2) and current literature (Chapter 3) has also been performed. Part II of the book focuses on the development of a novel model named Economic Risk, Resources and Environment (ERRE). ERRE is a larger and more detailed model than the World3, that includes finance, energy, food, and climate systems. The aim is to tackle both political problems related to resource availability in the short time scale (one to five years), as well as stress-test long-term scenarios and risks emerging from the interaction between the dynamics of growth and global resources limits until the end of this century.

The ERRE model has been formulated based on the work of Professor Jay Forrester in the 1970s and early 1980s. In particular, it is a formal update on the PhD Thesis of Professor John Sterman from the MIT School of Management, while integrating a food system based on the World3–03 land structure. During the modelling process, many updates based on current state of the art, in particular around the structure of financial flows and closed loop economic system, have been performed.

Part II of the book starts from a detailed review of the economic modelling literature, while comparing the system dynamics approach to other economic modelling methods (Chapter 4), and is followed with a general description of the ERRE model (Chapter 5). Chapter 6 provides a review of the dataset used to calibrate the model, and a statistical validation of the model output with the dataset. In addition, short-term shock scenarios are assessed, and long-term stress testing, to explore the dynamics of the world economy within the limits of the planet by the end of the century, is performed. The analysis is performed under deep

uncertain conditions, while engaging in the debate of uncertainty and fat-tail extreme scenario risk assessment. The ERRE model simulates from the year 2000 to 2030 to capture short-term shock dynamics, and extend the simulation until the year 2100 to capture long-term risk fat-tail scenarios. Both Chapters 5 and 6 are extended with supporting online material describing the structure and equations of the ERRE model in detail, and some key leverage behavioural tests performed on the ERRE model, to address how its dynamics compare to economic literature. All these are accompanied with the entire model, at the https://doi.org/10.25411/aru.10110710. The book concludes with our thoughts and proposals to engage in global system change both from a top-down approach to decision making, and from a bottom-up businesses and citizens' perspectives (Chapter 7).

The models are presented in order to welcome criticism from the reader. We are interested in making our models transparent and accessible. We believe that through questioning the limited structures of the models presented here, a system's view on the current state of the world can be reached. Most important we encourage debate and feedback, which ultimately, improve the models as well as change our mental models. Please take your time to read this book and be open for changing your view on world systems.

Part I

World models and limits


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1 The first formal world models

"What we meant in 1972 in 'the Limits to Growth' and what is still true, is that there is simply no endless growth in a finite planet" (Meadows 2012). The need for developing a world model was recognised and actively encouraged by the Club of Rome (CoR) in 1970 (Club of Rome 1970). The CoR is an informal, multinational, non-political group of scientists, intellectuals, educators, and business leaders sharing a common vision and concern for the future of humanity. It was formed in 1968 at the instigation of Aurelio Peccei, an Italian anti-fascist industrialist (Pauli 1987; Meadows et al. 1972). With the aim of engaging in the social problems generated by humankind and finding a way to create an economic paradigm that could generate sufficiency for all in the indefinite long term, they gained global visibility after their first report entitled 'The Limits to Growth' was published in 1972 (Meadows et al. 1972).

After decades of prosperous global industrial and business activities and an unprecedented accumulation and spread of capital and technology worldwide, it became clear that such an orthodox approach was also causing problems that would require a different way of thinking from that used to generate such 'prosperity.' They named such a concept the 'problematique of mankind' and referred to it as the "fragmentation of reality into closed and well-bounded problems which creates a new problems whose solution is clearly beyond the scope and the concepts we customarily employ" (Club of Rome 1970, p. 13). Today, the CoR has its headquarter in Winterthur, Switzerland, and involves more than 100 members ranging from heads of state, UN bureaucrats, high-level politicians and government officials, diplomats, scientists, economist and business leaders around the globe. They all share a common mission: "to act as a global catalyst for change through the identification and analysis of the crucial problems facing humanity and the communication of such problems to the most important public and private decision makers as well as the general public" (Weizsäcker 2014).

The first world computer model was driven by the need for a unifying integrated vision that could be shared among collaborating countries and economies that were getting bigger, more complex, more intelligent, at faster increasing rates, but were still based on resources extraction, unable to cope with (probably being the cause of) social and environmental problems, including overpopulation,

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