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Scientific Models

Red Atoms, White Lies and Black Boxes in a Yellow Book

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Preface

As biomathematicians, we work in the borderland between different sciences. Not only between mathematics and biology, but we have also discussed scientific problems with chemists, physicists, computer scientists and medical doctors. During such discussions on scientific questions, methods and conclusions, we have on several occasions been struck by the difficulty of establishing a connection with scientists from other disciplines. An obstacle in this interdisciplinary dialogue has often been our diverging views on the concept of "scientific models". The problem was in some cases made worse by the fact that we did not recognise our differing views, and therefore did not even discuss what each participant in the project actually meant by a "model".

The purpose of this book is to avoid such confusion and to facilitate interdisciplinary communication, which these days is becoming more and more common. Our aim is not to convey and advocate a typical or consensus model within the natural sciences, but rather to show the diversity of models that exist within science. Each discipline has its own methods and tools, and since modelling (often tacitly) is central to research, it is necessary to have a comprehensive understanding of the topic if interdisciplinary work is to be successful.

Another intention with this book is to provide a basic and broad introduction to modelling and to describe how it fits into contemporary scientific practice. As such it is intended for students in all fields of natural science. We were never during our education offered this kind of comprehensive introduction to models and modelling. Instead it is something that we, like many others, have picked up in a piecemeal fashion, during courses and by reading the scientific literature. Our hope is that by offering the reader a solid introduction to the topic they will have a head start that will benefit them in the future.

Since modelling spans all areas of science it is impractical to provide an exhaustive description of the topic. Our intention is not to provide a complete philosophical analysis of the topic or to carry out an in depth historical analysis of the concept, but rather to make it accessible to researchers, students and the general public.

During the course of writing this book, we have been helped by a number of knowledgeable and generous people: Martin Nilsson-Jacobi, Helena Samuelsson, Edvin Linge, Johanna Johansson, Henrik Thorén, Bengt Hansson, and Jonatan Vasilis och Staffan Frid. Lastly, we would like to thank our editors Eva Hirpi and Olga Chiarcos, and all the scientists that we have interviewed.

Gothenburg
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Prologue

On 16th September 2008, on the eve of the coming credit crisis, the Federal Reserve announced that they had created a secured credit facility of almost $85 billion in order to prevent the collapse of one of the largest insurance companies in the world, the American Insurance Group (AIG). The reason for this move, caused by an enormous deficit in liquidity, was the trade in credit default swaps (CDS) that AIG had been engaged in since the late 1990s. In the essence, CDS is an insurance which guarantees the buyer a certain compensation from the seller if a specific third party goes into bankruptcy and defaults. The initial intention of this financial instrument was as a means for companies to protect themselves against the default of corporations to which they themselves had lent money, but soon it was realised that this new financial derivative was highly lucrative and CDS were created and sold that had little to do with debt protection and more to do with financial speculation. This derivative evolved, and around 2004 AIG started selling CDS that were not designed to provide protection against a simple default, but to provide insurance against securities called collateralised debt obligations, a collection of debts such as house mortgages, car loans and credit card debts. In order to safe-guard them against the excessive risk and to price these complex derivatives, AIG used mathematical risk models to assess the probability that a payment to the buyer of the CDS had to be made. What the models did not account for, however, was that the underlying value of the collateralised debts would fall, in which case AIG was obliged to pay the buyer of the CDS additional money in the so-called collateral. This is precisely what happened in the early days of the credit crisis when the trust in collateralised debts plunged: first Goldman Sachs demanded $1.5 billion in collaterals, followed by Barclays PLC, the Royal Bank of Scotland and many others. But AIG was considered too big to bust and by early 2009 U.S. taxpayers had provided over $180 billion in government support to AIG. Using mathematical models to assess a risk was not invented by AIG; they have been in use since the 1970s. These mathematical tools are used by all major banks and investment companies, but the case of AIG shows what can happen if they do not work as expected: the losses can become enormous.

Although similar failures threaten the entire financial system, these problems are diminished when compared with what humanity faces when it comes to the climate of the planet. The causes, the magnitude and the effects of current climate change are still hot topics, and the different camps in this debate are rounding up their arguments, often, but not always, with scientific backing. How much we need to reduce our carbon dioxide emissions and how high the taxes should be on fossil fuels depend on the effects that we assume these will have on the climate. Simply put, increased emission of greenhouse gases leads to changes in the atmospheric composition that disturbs the radiation balance of the planet, which in turn gives rise to an increase in the average temperature and warmer oceans. When the temperature of the oceans increases, their ability to absorb carbon dioxide is reduced, which leads to an escalating greenhouse effect; but it also leads to increased formation of clouds, which reduces the amount of incoming radiation. The climate is affected by numerous such feedback mechanisms, the effects of which are almost impossible to comprehend. Together they create a web of interactions in which cause and effect might be difficult to distinguish. How should we scientifically approach such complex and critical questions? It is not possible to perform full-scale experiments with the atmosphere in order to study the effects of emissions. Instead an efficient approach is to study models of the climate, which can be used in order to simulate different emission scenarios and so estimate the impact on the future climate.[1] This data, together with a joint agreement on what constitutes acceptable changes in the climate, makes it possible to determine policies on emissions of greenhouse gases. This means that models of the climate to a large degree influence our political decisions, which in turn has a direct impact on our daily lives in terms of taxes on petrol, the price of electricity, etc.

In order to fully understand the ongoing political debate and current scientific inquiry, it is necessary to have a clear understanding of what models are and how they are used.

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[1] See e.g. the collection of climate models that the UN panel on climate change, IPCC, has assembled: http://www.ipcc.ch.

Introduction

Using models as a means to investigate the world and do science became popular during the 19th century, chiefly within physics when ideas from classical mechanics were being applied to other fields within physics. The idea or concept of a model is however considerably older and derives from the Latin word *modellus*, stemming from *modulus*, a diminutive form of *modus*, meaning a small measuring device. Apart from the scientific meaning the word, "model" also has a colloquial meaning, where it refers to how something should look or how some procedure ought to be carried out. An example of this is decision or allocation models in politics. The difference between such models and scientific models is not that the latter are imprecise or subjective, but rather that they aren't simplifications of reality. In contrast to scientific models they describe an ideal state of affairs and prescribe how something should look or be carried out. The easiest way to delineate these two conceptions is to view decision models and their like as archetypes, while scientific models function as simplifications.

In the sense of a description of how something is constituted or works the word model also applies, at least to some degree, to the world views that existed before the scientific revolution of the 18th century, such as the geocentric model of the solar system. An important difference between this use and the modern concept of a model is that the scientists of antiquity and the Middle Ages didn't consider their models as simplifications or idealisation of a more complex world, but rather as direct representations of reality. In this sense the pre-modern concept of a model lies closer to models as ideals, and not models as simplifications. It is also worth mentioning that the word model has had its current meaning only since the beginning of the 20th century, and that before then it was used exclusively to denote actual physical models. What we today call scientific models have historically been denoted idealisations, abstractions or analogies. For the sake of simplicity we will resort to the modern usage even when discussing historical facts.

The two examples presented in the prologue stem from two very different parts of society, and their purposes and aims are quite different. In the case of financial derivatives, models are used in order to estimate their value in the present and a short time into the future, while models of the climate are meant to produce predictions a

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