# Introduction

At the beginning of 1970, Amartya Sen prepared an anthology of selected readings in *Growth Economics*. What qualified the collection for publication with Penguin Books, known for inexpensive paperbacks, was its promise of a larger audience. While the field of growth economics did not even exist ten years earlier, it was now so central to the study of economics that Sen could note that "an undergraduate can no longer go through his economic theory course without meeting 'the rate of growth' face to face and without noticing its well-cultivated, if somewhat wayward, charm."[1] Straining to finish his survey-like introduction, he wrote a letter to Robert Solow, a former colleague at the Massachusetts Institute of Technology (MIT). Solow was well known for a model he had published in 1956. This model had been essential in stabilizing the specific, "technical" notion of a "rate of growth" that Sen talked about. In his message, Sen thanked Solow for clarifying in previous correspondence that the motivation of the model "was to trace full employment paths."[2] This clarification concerned the very status of the mathematical model as a "model." It could be read both as representing the actual workings of capitalist economies and as sketching some imaginary world that was purely hypothetical or could possibly be established in the future. In his reply, Solow conceded that "my general discussion in the 1956 article was ambiguous, for the simple reason that it wasn't clear to me at the time exactly what I was doing."[3] While Solow viewed his fifteen years younger self as somewhat confused, I read this anecdote differently. It attests, in a refreshingly honest manner, to the essential ambiguity of models. It is widely held that mathematical models made economists formulate their theories in a determinate and precise way. But their mathematical forms needed to be given "economic" meaning. At the same time, these forms essentially framed what "economic" meant. As for Solow, it took him some time to settle on what his model was all about.

The exchange points our attention to the tricky connection between models and a world outside their narrow confines – not only in economics but in many other fields in the arts, sciences, and engineering that involve languages and practices of "modeling." In principle, as the philosopher and historian of science Marx W. Wartofsky has noted, "anything may be taken as a model of anything else." The essential feature of what he has called a "modeling relationship" is that "it is *being taken as a model* which makes an actual out of a potential model."[4] In this book, I want to find out what made Solow's model a "model" and what that meant. I do so from a historian's perspective: Attending to other forms of economic knowledge-making and their settings between the 1930s and 1960s helps me think of modeling as a concrete practice and investigate the model's specific material and medial characteristics. At the same time, this approach allows me to tell episodes from the history of "growth" as an economists' problem. Overall, this book seeks to contribute to scholarship puzzling over the character, relevance, and effects of economic abstractions. My central argument is that models were more than figures of thought, expressions of social imaginaries, or rhetorical strategies. Due to their specific mathematical forms and to economists' way of treating them as tools, they exhibited certain practical qualities that made them rather efficient carriers of a specific way of reasoning. The central ambiguity and openness that characterized their status as models decisively contributed to their dissemination. As did Solow in correspondence with Sen, economists throughout this book emphasized that their models were *merely* models – stylized constructs, heuristic devices, tools for investigation. And yet, it was precisely such framing that allowed Solow's model to be employed in a variety of ways and unfold its suggestive power, irrespective of the modeler's intentions. Ultimately, it turned into a model of what it means to think like an economist.[5] The ambiguity it already featured on Solow's desk remained. "At any rate," Sen replied, "others have read much more into your 1956 model."[6] Perhaps in an attempt to control the model's openness, he added a footnote in the published anthology, quoting the modeler's own motivation that "the idea is to trace full employment paths, no more."[7]

## A SIMPLE MODEL OF GROWTH

As one of several formulations of a "neoclassical growth model," Solow's model is most commonly credited with "explaining economic growth and the long-term effects of economic policy" and with "illuminating the importance of innovation and technological progress to society's increasing wealth."[8] In "A Contribution to the Theory of Economic Growth," published in the *Quarterly Journal of Economics* in 1956, specific notions of "explanation" were at play. In a nutshell, the "simple model" featured the relation between the growth rates of the variables "output," "capital," and "labor."[9] While labor was given outside and independently of the model, capital could vary and adapted flexibly to the given amount of labor in order to ensure the most efficient output. The result was a self-sustaining equilibrium expressed in the form of a linear differential equation: A state of growth determined only by output and saving, in which both capital and labor were fully employed. Consequently, population growth or capital investment were not enough to increase this optimal growth rate. Instead, it could only be changed through additional factors that were not part of the model, such as "technological change." The model's simple appearance provided a rather efficient view of economic growth, drawing a line between a clean, well-ordered inside and a messy outside of all kinds of things that were excluded from analysis. A year later, in 1957, the model figured as an instrument for measuring economic growth and its sources. It estimated that technical change was responsible for almost 90 per cent of growth since the turn of the century.[10]

Soon, the "Contribution" found its professional readership. In contrast to other economists' works in the 1950s, it was not likely to be read by lay readers. It was, as a commentator noted, one of the more "technical papers, not suitable for leisurely general reading."[11] Heavily discussed within the realm of economic theory, it was singled out as the "most important paper" that contributed to a "major revision" of contemporary growth theory.[12] It became a constitutive pillar of American mainstream economics that dominated the profession until the 1970s and frames economic knowledge, in academe as well as policy-related realms, to the present day. In 1987, it earned its constructor the highest accolade of the profession, the Swedish national bank's Prize in Economic Sciences in Memory of Alfred Nobel. Established proponents of economics enthusiastically celebrated "the Solow model" as being "at the back of all economists' minds in approaching growth theory." It was said to have provided not only "an engine of analysis" but nothing less than "the organizing structure" of a variety of disciplinary fields – from development economics to international trade and public finance.[13] At the same time that Solow's model experienced a striking success, it was confronted with the most fundamental criticism. In fact, if success means that it was received and discussed widely, it had an equally successful life in the eyes and hands of its critics. The model attracted criticism for the utter unrealism of its assumptions, the provision of tautological knowledge, and the ideological veiling of capitalist destruction. It was dismissed for failing to explain growth and to provide an understanding of why economic development was uneven. In this way, Solow's model also became a symbol for economists' disinterestedness in the economic world, and an exemplar for the discipline's shaky scientific foundations.

Indeed, what a curious world this model presented. It depicted the relation between capital and labor, yet it excluded questions of power between social formations. It spoke of a community, its production, and growth. Yet there were no workers on factory floors, no investment decisions by managers, no material transformations. There were no nonaugmentable things such as energy or land, no environmental depletion. There were no unpaid activities like the rearing of children. And there was no money. To interpret the mathematical equations in terms of a physical economy required a series of assumptions regarding its space and time. Most importantly, it presented a world of "perfect competition," in which the fully flexible working of a market ensured equilibrium. There were no failures to coordinate, no overproduction, no underproduction. At each moment in time, everything that was produced was immediately either consumed or saved and invested. The assumption of "perfect foresight" established that future developments of prices and interest rates were known in the present. There was no uncertainty, no risk. In this frictionless cosmos, nothing essential evolved. The mathematical economy changed only in scale, not in composition – a ceaseless cycle taking place at one point in time. Historical dynamics and contingency were excluded. This list of absences can of course be continued.[14]

What was it that made this utterly frictionless world so appealing to economists and soon to other academics, policy-makers, and professionals? In the eyes of its contemporary theorists, what set the model apart was not some novel idea. That growth was not entirely dependent on capital accumulation had already been theorized in different ways. What made this model so attractive was precisely its specific format. Sen's introduction lauded Solow's model for its "beautiful simplicity," adding to a long line of appraisals that denoted it "an ingeniously simple yet extremely useful model for the examination of various aspects of the problem of growth," which is how one of the early readers described it.[15] The trouble with statements like this is that the qualities of being "simple" and "useful" depended on their relation to other forms of growth knowledge that were around. How was the problem of growth formulated such that, both in the eyes of contemporaries and in retrospect, Solow's model could provide a simple and useful means to investigate it?

## PROBLEMATIZING GROWTH AT MIDCENTURY

Solow's model equipped the postwar vocabulary of growth, development, and productivity with an efficient image of a manageable mechanism that led toward an ever more prosperous future. By 1956, growth had already become the center of American political economy, guiding both domestic policies and Cold War geopolitical strategy. The "eschatology of peaceful prosperity," as Charles Maier has framed it, formed the core of American identity as a liberal capitalist nation.[16] Transgressing party lines, private enterprise was seen as the very foundation for rising national output; government was assigned the status of a neutral arbiter deciding in the interest of growth. The politics of growth and productivity built on the rising importance of economic language and knowledge within government institutions since the beginning of the century. In the United States and elsewhere, it subjected policy-making to a primarily economic evaluation; public expenditures were mainly legitimized by their contribution to growth – a synonym of progress.[17] The expansion of the economy became the primary goal of national economic management, achievable through increasing efficiency and rising consumption and decoupled, for instance, from any limitations through natural resources.[18] The career of Solow's model went hand-in-hand with the "economic miracle" of the postwar golden age of growth that saw rising production and decreasing unemployment as well as a rise in carbon emissions and decreasing biodiversity. Much of the research surrounding it was financed by the notorious Cold War knowledge institutions. It fit a postwar climate of anti-communism as well as the forms and procedures of high modern bureaucracy. In the most straightforward "biographical" sense, it may have had its beginnings in Cold War culture. But it decisively related to earlier forms of economic knowledge as much as it contained various potentialities for future engagements with growth.

That Solow's system of mathematical equations was plausible as a "model of growth" depended on its fit with existing economic knowledge. First and foremost, its variables related to the statistical entity of the economy, a scientific-administrative object that already exhibited historical depth. Shaped by the rise of the nation state, the associated military planning, and early twentieth-century managerialism, governmental statistics gave new form to older visions of the economy. Since the seventeenth century, it had been presented as a closed and self-regulating system. Whether in encyclopedic, organic, mechanic, hydraulic, or bookkeeping form, portrayals of the economy not only made it intellectually manageable but also prompted action to realize that order.[19] Actualizing earlier displays of the economy, the postwar era established an intricate knowledge infrastructure based on metaphors of flows and cycles in which goods, capital, and work circulated.[20] While long-standing ideas about the flourishing of the whole (such as the growth of the wealth of nations or the improvement of productive techniques) remained central parts of governmental thought, the very objects of inquiry and intervention differed considerably.[21] It was still about the performance of a system as a whole, but now that system had the money-based form of an aggregated macroeconomy. The most prominent numbers in this regard were the national income and its reformulations, the gross national product (GNP), and the gross domestic product (GDP). These metrics featured the national economy as a closed entity of interdependent statistical parameters that was amenable to administrative action.[22] Drawing on longer-standing forms of economic knowledge, Solow's model bolstered the belief that stable growth could be created and sustained. Merging with other midcentury tools of governance, it gave the relations between the growth rates of national product, capital, and labor statistics.

When working on this book, I wanted to gain a better understanding of the knowledge that provided "growth" with its specific form. Genealogies of the economy have often focused on the broader problematizations of that entity as a central administrative–quantitative category. In a Foucauldian vein, they investigated the historical processes of how and why something previously unproblematic turned into a problem and became the object of social regulation – scientifically, ethically, and politically.[23] While these approaches emphasized the crucial role of economic knowledge tools for a liberal governmentality, the specifics of these instruments have rarely come to the fore. This book focuses on the characteristics of models and measurements of growth. It does so by investigating the problematization of the growing economy in economic *research*. This does not need to imply the perspective that economists' problems are autonomous from those outside their field's boundaries. There is no doubt, certainly not for the historical actors themselves, that their work intensively interacted with governmental interest. It was prompted and funded by governmental institutions; in turn, their renditions of the growing economy made the very phenomenon to be governed appear visible and amenable.[24] Looking at how different tools of modeling and measuring shaped the scientific problematic of growth, this book takes inspiration from a branch of history of science that has focused on how things (as diverse as dreams, the self, or atoms) gained scientific interest, how they turned into objects of scientific inquiry, and how they lost scientific attention. In the process, this literature has argued, phenomena became more or less real, depending on how "densely they are woven into scientific thought and practice."[25]

The measurers and modelers of the following pages were aware that their research was not in the first place dealing with some world out there but rather a matter of "phenomenotechnique."[26] Framed by Gaston Bachelard, the concept emphasizes the notorious difficulty to clearly differentiate between tools and phenomena when they are transformed into scientific problematics.[27] The growing economy that was assembled and scrutinized in the offices of national accountants, the mainframe computers of input–output researchers, and the notebooks of MIT's modelers was not a phenomenon of the life world. What economists denoted their "instruments" embodied theoretical ideas, conventions, normative judgments, beliefs, and imaginations, which all contributed to realizing the phenomenotechnical growing economy.[28] The problematics of growth research consisted of mathematical variables, correlation coefficients, and statistical parameters. In this sense, the growing economy that Solow's model depicted was already a scientific object that constituted a mesh of earlier and new threads, disregarding some and actualizing other elements of previous research objects.[29] Most importantly, it spoke to the variables in time series data of national product, capital, and labor. Built on similar assumptions, the model neatly fit the dominant empirical problematization of economic growth. It inscribed itself into an infrastructure of knowledge, in which models and data mutually stabilized each other.

In her review of works historicizing economic growth, historian Venus Bivar wondered whether the difficulty of merging the history of statistics with newer approaches to the history of capitalism came from a difficulty "to marry the material and the abstract."[30] While this book will not provide such warranted synthesis, it does seek to concretize the abstract in treating models and measurements of growth as deeply entrenched in research practices that were both discursive and material. The shaping and reshaping of the growing economy involved not only intellectual considerations but also practical requirements, institutional backing, and public financing. Paying attention to the nitty-gritty of the tedious phenomenotechnical work that went into the numbers of national accounts, productivity measurements, and input–output analysis allows me to feature Solow's model as part of a process of giving form to the problem of growth and thereby reframing that problem in a specific way. From this perspective, Solow's model contributed a further leap in both abstraction and concretization. Presenting growth as a simple mechanism, it carried the objectification of the economy to extremes. The model was used as a highly efficient gauge, detached from previous attempts to get closer to the material realities of production, separated from the intricate work of making numbers, and ignoring the contexts and weaknesses of the underlying empirical material. It fortified the idea of the economy as a separate sphere that was independent of all things social, cultural, political, and temporal. Doing so, it eased the perception of growth numbers as a glimpse into a world *out there*. This somewhat paradoxical effect was not simply a matter of continuities and breaks from earlier instantiations of the growing economy. Rather, it derived from a decisive transformation: The reformulation of economic growth in terms of a model and its embedding into a practice of modeling.

## MODELS AS MULTIFARIOUS ARTIFACTS

"Modeling is an age-old business," an operations researcher noted, thinking of the "clay models of the great pyramids at Giza or a wooden model of Noah's ark."[31] Indeed, practices of modeling, designing, blueprinting, planning, and sketching have a long history. But the history of mathematical modeling as an epistemic practice is decisively shorter, the history of mathematical modeling in the social sciences even shorter, and the history of talking about mathematical economic models in terms of material objects shorter still. Only in the middle of the twentieth century were mathematical models rather than mechanical analogies widely seen as the stuff of modern science. Only then did it become customary in fields of applied mathematics to use the term "model" and speak of "modeling" as the prime scientific activity.[32] In the aftermath of wartime planning, a larger movement of social scientists, among them economists, also adopted the language of modeling. Their use of the term "model" was characterized by a diversity in practices stretching from cybernetics to information theory, from systems analysis to game theory, from operations research to systems engineering.[33] The 1960s saw a veritable boom of the use of the term for a whole variety of things: Mechanical models, theoretical constructs, pictures, diagrams, computational models, hypothetical models, copies, prototypes, mental constructs, material models in museums and for teaching as well as logical models that had no reference outside language. What the contemporary observer Wartofsky called a "model muddle" was not only semantic but also ontological. It related to both the status of whatever was labeled a model and the status of the things it was said to represent – encapsulating the exchange between Sen and Solow above.[34]

Scholarship in the history of science has shown how larger postwar developments made it easy and attractive for social scientists to problematize their objects in terms of mathematical systems and dispense with other approaches. As part of these shifts, one instantiation of "the economy" was a perfectly efficient, optimizable system of simultaneous equations, which provided postwar economics with one of its major research objects. Historians have given particular attention to to game theory, general equilibrium theory, operations research, Cold-War interdisciplinary rationalities, mathematical economists' flashy cybernetic imaginaries, and the puzzling emphasis they put on the epistemic virtues of mathematical beauty and elegance.[35] This book also relates to the analytical frameworks of formalist economics and the impact of the digital computer, involves a partly similar personnel, and sometimes sets the storyline at overlapping institutions. At the center, however, is a specific practice and language of modeling that aimed to draw on quantitative knowledge, related more strongly to prewar economics, adapted a more antiquated kind of mathematics, and connected "simplicity" with empirical and political "usefulness" rather than formal "elegance." Distancing their projects from the abstract aesthetics and intricate makeup of axiomatic systems of general equilibrium theory, the mathematical economists in this book thought that their models promised to make economic theory more realistic and closer to empirical relevance. And in contrast to some of their contemporaries, whose enthusiasm for the computer fed into a matching penchant for complexity, they wanted to keep the complexity of their models to a minimum. Their views testified to a multiplicity of model understandings in the sciences, in particular when it came to the varying status of mathematical models between concrete objects and abstract entities.[36]

The modelers in the following pages adhered to the view that mathematics was the "language of modern science," which only made it natural for them to turn to the archive of mathematical formalisms. In the first place, to put it very bluntly, making economics "scientific" to them meant something like reframing ill-defined problems by using the abstract and

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precise language of mathematics and making the underlying presumptions explicit. The clear-eyed scientific economist explicitly stated assumptions and definitions. These set up a logically consistent mathematical formulation. Conclusions were clear-cut. Utterings in this vein, however, made up only one layer of economists' model talk. When they went into what they were *doing* in their research, it often came across as a concrete activity of working toward and with some kind of artifacts. In this vein, historian of science Mary S. Morgan has described economic modeling as a "style of reasoning" that consists in constructing and manipulating "small mathematical, statistical, graphical, diagrammatic, and even physical objects." Models, in this sense, are not abstract structures but concrete artifacts that are deliberately made in a process that involves articulated as well as craft-based knowledge.[37] In the following chapters, economists, especially Solow, will indeed refer to their modeling work as an art and handicraft. Such statements, often made in a fairly casual way and rarely part of a formalized methodology, make up a second layer of model talk. Here, modeling appears as a concrete activity of making something new and artificial and of tinkering and toying with it. The relation of the resulting knowledge to a world outside the confines of models was rather informal. Model knowledge was not supposed to be true or lead to exact forecasts or precise statements about probabilities. The two layers of model talk did not necessarily agree with one another. But they both belonged to a practice of modeling that is understood here as involving the *work* as well as the *performance* of economics as a modeling science.

Taking seriously economists' model talk as a part (and not simply as a description) of their modeling work opens the possibility to investigate how the power of economic abstractions derived from the way they were built and used as artifacts. For one, it highlights models' difficult relation to a reality outside their confines. Solow's "Contribution" did not present any empirical study – its results merely derived from the constructed model, and neither the model nor its assumptions were "tested." The growth rate it presented was derived from a mathematical equilibrium system, rather than calculated from numbers of the past. When the model was used as an instrument of measurement, it served as a means to interpret given data as if the numbers resulted from a world that looked like the model. Whatever was not part of the clean cosmos (the ever-extendable list of absences I sketched in the first section) was stashed away in a "residual," which now captured the messy outside of the model in a separate error-term. From a methodologist's standpoint, Marcel Boumans has noted that it is through