Progress in Economics

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Abstract

In this chapter, we discuss a specific kind of progress that occurs in most branches of economics today: progress involving the repeated use of mathematical models. We adopt a functional account of progress to argue that progress in economics occurs through the use of what we call "common recipes" and model templates for defining and solving problems of relevance for economists. We support our argument by discussing the case of 20th century business cycle research. By presenting this case study in detail, we show how model templates are not only reapplied to different phenomena. We also show how scientists first develop them and how, once they are considered less useful, they are replaced with new ones. Finally, our case also illustrates that it is not only the mathematical structure that is reused but that such reuse also requires a shared conceptual vision of the core properties of the phenomenon to be studied. If that vision is no longer shared among economists, a model template can become useless and has to be replaced, sometimes against resistance, with a different one.

1. Introduction

In this chapter, we analyze how economics progresses by discussing not only when progress occurs in economics but also when it does not. As in most disciplines, economics as a field is a patchwork of subfields, many of them with their own methodology, and is not as unified as has sometimes been claimed. Therefore, to discuss progress in economics, we first have to choose the subfield in which progress is to be described. In the following, we focus on those subfields in economics that predominantly use models. Because modeling is the most common methodology in economics, we are able to cover most parts of the field of economics.

Since the middle of 20th century, economics has become a modeling science (Morgan 2012). Economic models have become "endemic at every level" (Morgan 2012, p. 2). The reliance on models also introduced a new way of reasoning to economics: "As models replaced more general principles and laws, so economists came to interpret the behaviour and phenomena they saw in the economic world directly in terms of those models" (ibid., p. 3).

Economists use a variety of models. Economic models can be mathematical, statistical, or diagrammatic, and even include physical objects that can be manipulated in various ways. To discuss whether progress occurs in economics, we also have to choose a subset of these and consequently limit ourselves to a discussion of mathematical models. The development and use of mathematical models is indeed representative of what large parts of economics does as a modeling science.

By analyzing progress in economics enabled by mathematical models, we also attempt to understand when progress is altered and how new methodological developments are considered to be potentially progressive. To do so, we draw on the recent literature on model making and application in philosophy of science to look at a case study from economics. We argue that progress in model-based economics occurs when a model is considered sufficiently useful to be reapplied to define and solve pending or new problems. Progress is disrupted when models are considered useless for those purposes and advances again when a model is developed that proves useful in this respect.

2. Concepts of Scientific Progress and Scientific Modeling

To fruitfully discuss how large parts of economics progress, we choose the functional approach to progress because it best captures the kind of progress accounted for in this chapter (see Part I of this volume for a detailed description of the four distinctive approaches to characterize scientific progress). Economics is chiefly a problem-solving science, in particular where model making and application predominate. We can even observe instrumentalist attitudes in economics which can best be captured by the functionalist approach. This is not to say that all progress in economics is functional, even in those subfields that draw heavily on models. Progress can also be theoretical. Indeed, other accounts, such as epistemic, semantic, and understanding-based approaches to scientific progress, are focused on how theoretical achievements enable progress. However, although economics has long made extensive use of theory, theoretical progress is no longer what economists primarily aim to achieve.

We assume that there is a consensus among economists that economic theory, that is to say general equilibrium theory combined with utility theory, has reached a stage at which no further refinement is needed. However, an uncritical view of economics as exclusively focused on progress produced by models is overly simplistic. General equilibrium theory and utility theory have changed considerably during the 20th century. For instance, utility theory was augmented by prospect theory, introduced to economics by the psychologists Daniel Kahneman and Amos Tversky in 1979; this shows a continuous commitment to theory in economics and a desire to develop the field further by developing new theory. However, as Robert Lucas (2004, p. 22), one of the most influential economists of the 20th century, claims, the progress one can find in economics is mostly technical:

> We got that view from Smith and Ricardo, and there have never been any new paradigms or paradigm changes or shifts. Maybe there will be, but in two hundred years it hasn't happened yet. So you've got this kind of basic line of economic theory. And then I see the progressive – I don't want to say that everything is in Smith and Ricardo – the progressive element in economics as entirely technical: better mathematics, better mathematical formulation, better data, better data-processing methods, better statistical methods, better computational methods.

We consider Lucas's view a representative and credible description of the overall disciplinary development of model-based economics from the mid-20th century onwards.

Lucas's understanding of progress shifts the focus from the role of theory to that of models, so that he sees a theory as "an explicit set of instructions" for making a model (Lucas 1980, p. 697). Yet, theorizing and modeling should be distinguished from each other. In economics, theories are general accounts assumed to provide truths about economic phenomena, whereas models function primarily as instruments of investigation (Morgan and Morrison 1999) and hence are made for specific purposes. A model is therefore validated by assessing how much or in what respect it can reach its purposes. These purposes can be meaningfully reconstructed as problems that models are meant to solve.

We consider Shan's (2019) "new functional account of progress," to provide a particularly useful framework for thinking systematically about model-based progress in economics.[1] One major advantage of Shan's account over traditional functional approaches is that instead of emphasizing only the problem-solving dimension of progress (Kuhn 1970,

[1] See also Chapter 3 "The Functional Approach: Scientific Progress as Increased Usefulness" in this volume and Chapter 6 "A Functional Account of the Progress in Early Genetics" in Shan 2020.

Lakatos 1970, Laudan 1981), he defines progress in terms of the usefulness of a particular scientific practice for problem defining and problem solving. To achieve progress, a scientific practice is useful when it repeatably define and solve problems. Consequently, this practice should provide a "reliable framework" for solving and defining more problems in other areas or disciplines (Shan 2019, p. 746). The repeatability and reliability of the process of defining and solving research problems is thus a prerequisite for recognizing its usefulness.

Shan characterizes progress as the successful application of frameworks that guide the process towards defining and solving new problems within and across fields and disciplines. He explicates the process behind problem defining as a sequence of problem proposal, problem refinement, and problem specification. He emphasizes what he calls a "common recipe" for a useful solution to indicate that the solutions provided by this framework do not have universal and stable characteristics, but that a solution consists of the following nonexhaustive list of components: a set of concepts employed in problem and solution; a set of practical guides specifying the procedures and methodologies as means to solve a problem; a set of hypotheses proposed to solve a problem; and a set of patterns of reasoning indicating how to use other components to solve a problem (Shan 2019, p. 745). Usefulness is thus defined as the repeated successful application of a common recipe to define and solve new problems. Hypotheses should not be narrowly construed as statements or propositions; they can also take the form of models. This is also how we can think of them when we apply this account to economics.

In this chapter, we start from the idea of thinking about problem definitions and solutions as common recipes to address how we can consider the parts of economics that progress through mathematical models. To specify the components of a problem's definition and solution in economics using Shan's idea of a common recipe, we combine ideas from the modeling literature to capture not only what economic models are but also how they are built, revised, and reapplied. These aspects help us specify the procedures and methodologies for solving problems in economics, the framework proposed by economic models to solve a problem, and patterns of reasoning indicating how to use other components to solve that problem.

We start from Paul Humphreys's account of understanding models as based on what he calls "templates," which are mathematical or computational forms that are flexible enough to be applicable to various kinds of target systems (Humphreys 2002, 2004, 2019). Generally, a template constitutes "a pattern that can serve as a common starting point for the development of a product but that can be adapted for the purpose at hand" (Humphreys 2019, p. 116, fn. 20). Humphreys uses his concept of a template to clarify how using such templates within one domain, such as a discipline or subdiscipline, aids "the acquisition of explicit knowledge and understanding, and to explore similar questions when they are applied across domains" (ibid., p. 114). Thinking of modeling as grounded on templates allows us to see how their application to other target systems within economics might ensure a repeatable process that leads to the definition and solution of new problems in the respective domain.

On Humphreys's account, templates are in the first instance subject independent, albeit to differing degrees. Whereas the models that are ultimately made from such templates represent specific target systems, the underlying template is general in that it lacks a specific interpretation other than that which is given by a general theory accepted in that domain. Therefore, templates are transferrable and applicable to radically different target systems, sometimes studied in distinct domains. While Humphreys has introduced various notions of a template, we draw on his recent definition of a 'formal template' (Humphreys 2019). A formal template is described as a mathematical form without interpretations beyond a mathematical one and of which the construction assumptions only have mathematical content.[2] Formal templates can be used to model phenomena only after undergoing a process of construction and specification. As examples of one-equation templates, Humphreys mentions the Laplace's equation, Poisson's equation, and the diffusion equation. Other examples of formal templates are statistical distributions such as the Gaussian, Poisson, and binomial.

A well-known example of a formal template from economics is the two-variable homogeneous function of the first degree $f(x,y) = Ax^{\alpha}y^{1-\alpha}$, also known as the Euler function. In economics, this function is better known as the Cobb-Douglas function, because it was originally used by Charles Cobb and Paul Douglas to define a production function representing the relationship between inputs for production and outputs generated on their

[2] Formal templates also include forms in formal logic or programming languages. In model-based economics, so far, they do not play any significant role.

basis.[3] This function became a template because it possesses the attractive advantage of displaying a direct relationship between its "elasticities" and "returns to scale." Elasticities in economics refer to the proportional change of some economic variable in response to a change in another, which can be expressed as $\left({\partial f}/{\partial x}\right)/\left({f}/{x}\right)$. For example, the elasticities of the Cobb-Douglas function variables x and y are represented by α and $1-\alpha$ respectively. They show how much an increase in the input factors influences the output or return.

The template account of models can capture how formal structures such as the Cobb-Douglas function are transferred within and across domains and used to define and solve several problems in economics beyond the problem they were originally meant to address. As we show below, many such mathematical structures are used in economics, which is why the template account applies well to the kinds of economic models we discuss here. However, to consider not only when functional progress in economics occurs but also when it does not, we must first understand why a specific template is chosen at all. Two additional aspects of templates are relevant. The first aspect is the frequently observed intertwining of the conceptual and mathematical dimensions of a template, which rests on the premise that templates are not neutral, contrary to Humphreys's account. The second aspect is the set of prerequisites for initial adoption of a template. This second aspect is particularly relevant to understanding progress when old templates are replaced by new ones. Both aspects are largely neglected in Humphreys's account of templates but are relevant to the integrative aspect of modeling in economics.

Building on Humphreys's account, Tarja Knuuttila and Andrea Loettgers (2016, 2020) capture the first element, the intertwining of conceptual and mathematical dimensions in a template, by proposing the concept of a "model template" as an alternative to the formal template account. They argue that a model template is a mathematical structure that is "*coupled with a general conceptual idea that is capable of taking various kinds of interpretations in view of empirically observed patterns in materially different systems*" (2016, p. 396; italics in original). To illustrate their concept of a model template, they studied the cases of the Lotka–Volterra system of nonlinear coupled differential equations and the Ising model. Their approach suggests that Humphreys's account should acknowledge the

[3] Although today it has many other applications, such as to define consumption, the Euler function is still called the Cobb-Douglas function after its first famous application. We follow this tradition in economics.

aspect of analogical reasoning to explain how templates are reapplied and even transferred across domains (Knuuttila and Loettgers 2020). They include this aspect because they consider the conceptual dimension coupled with the mathematical structure to specify some characteristics of potential target phenomena. Without taking analogical reasoning into account, it will be difficult to explain what drives the application of a formal template both within and across domains; in their view, scientists can do so because they identify these characteristics as shared across target domains.

More specifically, according to Knuuttila and Loettgers (2020, p. 128), useful templates embody a vision of the phenomenon exhibiting a general pattern for the study of which the template, including the underlying conceptual idea, offers appropriate tools. For instance, in the case of the Lotka–Volterra model, the model template provides a framework that "renders certain kinds of patterns as instances of cooperative phenomena [i.e., the conceptual idea] coupled with associated mathematical forms and tools that enable the study of such phenomena" (p. 135). Seeing various kinds of systems as instances of a familiar general pattern captured by this conceptual idea enables scientists to apply the template to different systems. It is particularly the conceptual side of the model template that mediates between the mathematical form and its various empirical interpretations. According to Knuuttila and Loettgers (2020, p. 135), this combination that model templates embody, of a conceptual vision of the phenomenon and a mathematical form, is what makes them attractive for reuse.

When we view functional progress in economics from the template view, it appears largely to occur when such templates are reused as common recipes to define and solve problems. However, before we discuss whether we can find functional progress in economics through the reuse of model template, we address the second aspect, the use of a new template, to capture the conditions under which progress is disrupted in economics. Generally, as we show below, progress is disrupted when the conceptual vision of the phenomenon has changed in such a way that the mathematical form is no longer considered to be sufficiently representative of the phenomenon in question. We address this second aspect by presenting a few accounts of model-making that complement the template account by focusing on the process of template making and can partly explain why a new template is adopted.

Morgan (2012) distinguishes four accounts of how models are constructed. The first was proposed by Boumans (1999). In this account, the process of model-making can be understood as analogous to recipe-making. The notion of a recipe encapsulates two ideas. The first idea is that economists choose a model's ingredients; these include theoretical notions, metaphors, analogies, policy views, mathematical concepts, mathematical techniques, stylized facts, and empirical data. The second idea is that these ingredients are integrated to create something new: mixing, shaping, combining, and molding them to create a new model. The final product may well not be what was envisioned at the beginning; recipe-making is a creative process. However, the resulting recipe can then be used for making other models to answer similar questions. For example, one wishes to find the business cycle mechanisms of two different economies. If we skip an ingredient or replace it with a different one, we obtain a new model that answers questions similarly to the old one. Some of the stylized facts may differ between the two business cycles. The cycles may have different periodicities. So, what makes the recipe useful is that it offers a template useful for developing other models.

The second account is Morgan's own (Morgan 2004). It rests on the view that model-making requires, first, imagination to hypothesize how the economy might work, and second, the power and skill to envisage that idea. A third account understands model-making as a process of idealization: a process of picking out the relations of interest and isolating them from any disturbances which interfere with their workings. The final account is on Mary Hesse's (1966) work, who argues that model-making depends upon our cognitive ability to recognize analogies and our creativity in exploring them. However, Morgan suggests that the point of modeling is not to recognize analogies but to create them. According to Morgan (2012, p. 25), what these four accounts have in common is "that forming models is not driven by a logical process but rather involves the scientist's intuitive, imaginative, and creative qualities." Although the second and third accounts emphasize the construction of a common vision as a necessary part of model-making, it is the first and fourth accounts that prove useful in thinking about the usefulness of economic models understood as model templates. This is because they capture the process by which new templates are developed to define and solve new problems.

We propose to complement the template account with these model-making accounts that explain why templates are adopted. They also provide a systematic way to capture how template-building can be a progressive step. However, they capture only one aspect of functional progress. Of course, being able to build a satisfactory template, and thus model, can be considered some form of progress. Whether a model can be considered satisfactory depends on whether it meets certain aims or criteria, such as satisfying theoretical requirements, representing certain facts, and being useful for policy (Morgan 1988). However, what is relevant for our argument is whether these models are a constitutive element of a satisfactory framework and thus provide a representative practice for defining and solving new or unsolved problems. The first and the fourth of the accounts discussed above implicitly indicate how this may happen. Boumans's recipe account suggests that the recipes can be followed to make other models for similar aims. The analogy account suggests that these models can be used as formal analogies to create other models for similar purposes. But both accounts only clarify the application of model templates once some similarity has been ascertained and acknowledged between certain aspects of the problems. Therefore, these accounts cannot explain why some models have been fruitfully applied to defining and solving problems of very dissimilar kinds. Neither can these accounts explain how models are applied to cases for which no similarity has yet been ascertained.

To understand the progressive aspect of the reuse of models, we need to complement the model template account with an account of model making that captures the idea that templates are not only complemented by a conceptual vision but can also co-define or shape this conceptual vision. Take the example of the Cobb-Douglas function presented above. It has found applications in various domains not because of similarities between such aspects as the phenomena in different domains, but because of its directly displayed relation between elasticities and scale: because of its neat mathematical features. It is these mathematical features that are conceptually considered useful for defining and solving new problems. In this way, these mathematical features create the similarities between two patterns.

3. A Case Study from the History of Modeling the Business Cycle

To explore how the model template account combines with the model building accounts to help understand functional progress in economics, we discuss a specific case of modeling in economics, that for macrodynamic phenomena such as the business cycle and growth initiated by Jan Tinbergen's methodology (Boumans 2004). Tinbergen's methodology included a vision of what business cycles are, a general template for modeling them, and a number of requirements prescribing how cyclical movements of the economy should be explained.[4] Tinbergen's methodology of modeling and the model template it provided can be understood as providing a common recipe for defining and solving business cycle problems in economics. This case shows how model templates are not only reused but also how scientists create models initially and how, once they are considered less useful, such old templates are replaced with new ones. Finally, this case illustrates that it is not only the mathematical structure that is reused but that such reuse also requires a shared conceptual vision of the phenomenon that underlies the phenomenon. If that vision is no longer shared, a model template can become useless and has to be replaced, sometimes against resistance, with a different one. This case underscores how the concept of a model template plays a key role in enabling functional progress in economics.

A good starting point for our analysis is Tinbergen's business cycle research in the 1930s (Boumans 2004). He was the first to introduce the methodology of modeling to economics by providing a common recipe for model building in business cycle modeling and later in economics in general. Tinbergen's methodology was based on James Clerk Maxwell's "method of formal analogy" (Boumans 2004). According to Maxwell, "we can learn that a certain system of quantities in a new science stand to one another in the same mathematical relations as a certain other system in an old science, which has already been reduced to a mathematical form, and its problems solved by mathematicians" (Maxwell [1871] 1965, pp. 257-258). Tinbergen introduced this methodology to economics in a 1935 survey article on recent developments in business cycle theory because he was interested in explaining the observed dynamics of an economic system. According to Tinbergen (1935, p. 241), the aim of business cycle theory is to "explain certain movements of economic variables. Therefore the basic question to be answered is in what ways movements of variables may be generated." To answer this question, one had to find the underlying mechanism, which he specified as "the system of relations [i.e., a model] existing between the variables" (p. 241). This system of relations "defines the structure of the economic community to be considered in our theory" (p. 242).[5]

[4] We understand a "methodology" here along the lines of Laudan's definition as a broad set of procedures, strategies and tactics used for the purposes of validation of scientific hypotheses as well as their heuristic advancement (Laudan 1984, pp. 3-5).
[5] Instead of "economic community," today we would use the term "economy," but in the 1930s, this latter term did not yet have its current meaning. The same applies to the term "model," which was not commonly used in the 1930s. Instead of this term, Tinbergen speaks of a "system of relations."

To find the mechanism underlying the dynamics of business cycles, Tinbergen emphasized that one needs to distinguish between the mathematical formulation of the mechanism captured by its defining equations, and the economic interpretation, or "sense" as Tinbergen called it, of these equations. According to him, "[t]he mathematical form determines the nature of the possible movements, the economic sense [i.e., the economic interpretation] being of no importance" in the first instance. The mathematical form could be reapplied to various systems because, for instance, "two different economic systems obeying … the same types of equations may show exactly the same movements" in variables (p. 242). However, whereas finding the appropriate "mathematical form" was essential, it was not sufficient to develop a business cycle theory. Their economic interpretation would ultimately be crucial because only the combination of both would reveal the significance of this theory for economics, or as Tinbergen wrote: "no theory can be accepted whose economic significance is not clear" (p. 242). As we show, this economic interpretation can be understood as the conceptual vision of the phenomenon accompanying a model template discussed above, and it did not come only after the mathematical form was determined, as Tinbergen suggested. We show that more is at stake than merely an interpretation of the model; it also includes an interpretation of the specific phenomenon, the business cycle, and its mechanism.

After surveying the mathematical forms available at that time to model what Tinbergen viewed as the mechanism underlying the business cycle, he arrived at the following template that captured his conceptual vision of the business cycle mechanism (Tinbergen 1935, p. 279):

$$\sum_{i=1}^{n} a_i p(t - t_i) + \sum_{i=1}^{n} b_i \dot{p}_t(t - t_i) + \sum_{i=1}^{n} c_i \int_{0}^{t-t_i} p(\tau) d\tau = 0,$$

where *a*, *b*, and *c* are coefficients, *p* represents the general price level, and *t* represents time. To ascertain that this general difference-differential-integral equation represents a business cycle mechanism, its parameters need to meet two "wave-conditions": The first condition is that the parameters should be such that the solution of this equation consists of a sine function; in this the time shape of $p(t)$ is cyclic. The second condition is that the cycle period should be much longer than the time unit and that its amplitude is constant. These conditions taken together imply that the summation of the coefficients c should be zero, so that $\sum c_i = 0$, and thereby reduce the kinds of mechanisms that are acceptable.

At first sight, Tinbergen's equation seems to be a good example of a template as proposed by Humphreys. It constitutes a mathematical structure without any a priori economic interpretation attached to it. However, Tinbergen developed this template with a clear conceptual vision of the main characteristics of the business cycle, as reflected by the mechanism captured by the model. Thus, his contribution is actually a good example of how the conceptual vision of the phenomenon, the mechanism coupled with the view that cycles should be endogenous and permanent, shapes the mathematical structure constituting the template. In other words, Tinbergen's template can best be described as a model template as proposed by Knuuttila and Loettgers.

Paul Samuelson turned Tinbergen's methodology into a more general modeling methodology for the field of macroeconomics, which became a new area in economics. Samuelson (1939, p. 78) considered Tinbergen's methodology as "liberating" when he wrote that "[c]ontrary to the impression commonly held, mathematical methods properly employed, far from making economic theory more abstract, actually serve as a powerful liberating device enabling the entertainment and analysis of ever more realistic and complicated hypotheses." In a four-page article, Samuelson discussed the dynamics of a simple four-equation model of an abstract economy to illustrate this methodology. As in Tinbergen's template, the dynamic behavior of the economy could be expressed by the reduced form equation of this four-equation model, which was the following second-order difference equation:

$$Y_t = 1 + \alpha[1 + \beta]Y_{t-1} - \alpha\beta Y_{t-2},$$

where Y represents national income, and α and β are some coefficients. The "qualitative properties" of the model, that is the dynamic characteristics derived from Tinbergen's conceptual vision, then depended only on the values of α and β. Samuelson showed that all possible combinations of the values of α and β lead to four types of behavior of Y: Y will "approach asymptotically" a specific value, "damped oscillatory movements," "explosive, ever increasing oscillations," and "an ever increasing" Y (Samuelson 1939, p. 77).

With his equation, Tinbergen had not only proposed a model template to be applied to the business cycle. He had also introduced a whole methodology of mathematical modeling, which was further elaborated by Samuelson for macroeconomics and which later became the foundations of mathematical economics. This methodology provided a common recipe for defining and solving problems. Textbooks appeared in which this approach was demonstrated. One of the best-known textbooks was Alpha Chiang's *Fundamental Methods of Mathematical Economics*, first published in 1967. According to Chiang, mathematical economics is "an *approach* to economic analysis, in which the economist makes use of mathematical symbols in the statement of his problem and also draws on known mathematical theorems to aid to his reasoning" (1974, p. 3, italics in original). Another important textbook was R.G.D. Allen's *Mathematical Economics*, first published in 1956. As Allen explained, "[t]he elements of macro-dynamic economic theory (Chapters 1, 2 and 3) show up the need for using difference and differential equations and for the description of oscillatory variation by means of complex variables and vectors (Chapters 4, 5 and 6)" (Allen 1959, p. xvi), clearly pushing Tinbergen's methodology. Beside the existing mathematical methodologies of static equilibrium analysis, comparative-static analysis, and optimization problems, both textbooks also contained mathematical economics in the Tinbergen–Samuelson tradition: a methodology for dynamic analysis that includes difference equations and differential equations and their combination.

Against this background, Tinbergen's methodology, as generalized by Samuelson, can be understood as a common recipe for studying dynamic economic phenomena, including a template coupled with a conceptual vision of the main characteristics of those phenomena. Textbooks such as Allen's and Chiang's can then be considered as recipe books that provide the formal templates. When dealing, for example, with an optimization problem, economists could use them to look for a recipe to tell them which kind of mathematical tools or concepts would be appropriate for which mathematical problem. For example, it became standard in economics to apply the Lagrangian equation to any optimization problem. So, Tinbergen's and subsequently Samuelson's methodology exemplifies the idea of a template (from the recipe book) plus a conceptual vision to study the phenomenon in question as crucial ingredients of a common recipe for defining and solving a diverse array of economic problems.

Catherine Herfeld and Malte Doehne (2019) give a characterization of the process of developing a scientific idea, which could be a new template, from its innovation to its application to concrete problems in a specific domain. They propose a typology of roles that scientific contributions can play in this process. Firstly, contributions can play the role of innovators, as Tinbergen's contribution does, which formulate a novel template. Secondly, they may be elaborators, as was Samuelson's contribution to generalizing Tinbergen's template, that clarify, adapt, and sometimes modify the conceptual, theoretical, or empirical scope of the template. The third role is that of a translator, such as Chiang's contribution, which adopt the elaborated template and modify it in such a way that it aligns with established frameworks and concepts in a specific domain so that it can be used for specific problems. Indeed, translator contributions sometimes provide concrete recipes for how an abstract template can be repeatedly applied to concrete and specific problems in various domains in what Herfeld and Doehne (2019, p. 43 f.) call a specialist contribution. We can understand the process sketched in our case study as following a similar sequence: the recipes resulting from elaboration and translation of a novel template are crucial in enabling the recurring application of the template to focused and specific problems and thus can lay the ground for functional progress in economics.

The case of Tinbergen's methodology shows how a template is applied to define and solve multiple problems following a common recipe. Furthermore, we can use this case to show that a template in this process is not reapplied on its own but that its reuse depends crucially on conceptual considerations and whether the underlying conceptual idea remains stable; in other words, it does not function merely as a formal template but as a model template. Although the methodology of using difference and/or differential equations to capture the dynamic properties of the business cycles can be understood as providing a useful common recipe for defining and solving problems in business cycle research, it also has some disadvantages that limited its use for defining and solving new problems in economics. A first disadvantage is that the stability assumed for the cyclical movement was too dependent on specific parameter values. Take, for example, a second-order differential equation. Whether the cycle is stable, gradually diminishes, or grows in amplitude is determined by the parameter of the first-order term. Tinbergen's wave conditions required that its value was zero. In discussing a business cycle model, where this issue played a role, Ragnar Frisch pointed out that "since the Greeks it has been accepted that one can never say an empirical quantity is exactly equal to a precise number" (Goodwin 1989, pp. 249-250).

To further see how the template was connected to Tinbergen's conceptual vision of the business cycle, a second disadvantage has to be considered, namely the assumption that the business cycle is considered to be endogenous, meaning that the existence of the business cycle is fully explained by the dynamic characteristics of the economic system alone. In economics, the dominant view has been that the economic system is a stable equilibrium system and that, as such, every position out-of-equilibrium would move back to equilibrium. This implied that the business cycle should be explained by exogenous factors. The disadvantage here is that the mathematics of difference and differential equations implied an endogenous explanation that was in conflict with the standard equilibrium view in economics and thus with an important methodological commitment of economics, which in turn called into question Tinbergen's conceptual vision of the business cycle. A third disadvantage of the Tinbergen approach is that observed business cycles do not resemble a smooth harmonic oscillator but less regular, that is to say more like a constantly changing harmonic, a cycle whose period lengths and amplitudes vary and whose shape is erratic.

These changes in the conceptualization of the business cycle as erratic fluctuations instead of a smooth harmonic and in the explanatory requirements as neither deterministic nor endogenous exemplify how disadvantages can hamper or even halt the reuse of a template because the template does not capture mathematically the general properties of the target system. To overcome them, Frisch's (1933) influential paper 'Propagation Problems and Impulse Problems in Dynamic Economics' demonstrated that the business cycle can be generated by an iteratively disturbed stable equilibrium system. Frisch's starting point was Tinbergen's template, a mixed difference and differential equation. However, this equation did not show how the cycles are maintained: "when an economic system gives rise to oscillations, these will most frequently be damped. But in reality, the cycles we have occasion to observe are generally not damped" (Frisch 1933, p. 197). Frisch introduced the concept of what he called "impulses" to solve this problem. He explained the maintenance of the dampening cycles and the irregularities of the observed cycle by the idea of erratic shocks repeatedly disturb the economic system. These impulses are then propagated through the system, represented by the mixed difference and differential equation, creating a behavior that resembled the observed business cycle.

By adopting a new conceptual vision of the characteristics of business cycles, Frisch replaced the model template of mixed difference and differential equations with a template that combined this deterministic system with a stochastic process. He assumed that $Q(t)$ denotes a damped oscillation that is the solution of the mixed difference and differential equation, t is time, and e_k represents the random shocks; then, the business cycle generated by Frisch's propagation and impulse model is:

$$y(t) = \sum_{k=1}^{n} Q(t - t_k)e_k,$$

where y is production. As Frisch noted, "$y(t)$ is the result of applying a linear operator to the shocks, and *the system of weights in the operator will simply be given by the shape of the time curve that would have been the solution of the determinate dynamic system in case the movement had been allowed to go undisturbed"* (Frisch 1933, p. 201; italics in original). In other words, the business cycle was a summation of weighted shocks whose weights are determined by the economic system. Frisch had a conceptual vision of the economic system as a dynamic system that determined the dynamic properties of the cycle but did not explain its continuation. According to him, the continuation of the cycle was explained by a sustained series of external random shocks.

Beside the three disadvantages of Tinbergen's model template outlined above, another reason why Frisch had developed a new template, which became known as the "rocking horse" model, is that Eugen Slutzky had suggested a "deeply worrying possibility" that "cycles could be caused entirely by the cumulation of random events" (Morgan 1990, pp. 79–80). In an article with the title "The Summation of Random Causes as a Source of Cyclic Processes" (1933, originally published in 1927 in a Russian journal), Slutzky discusses whether it is "possible that a definite structure of a connection between random fluctuations could form them into a system of more or less regular waves" (p. 106). Slutzky showed that it was indeed possible. He used a rather simple model, a 10-item moving summation of a random number series, the last digits of the numbers drawn for a Russian government lottery loan, in this equation: e_k: $y(t) = \sum_{k=1}^{10} e_k + 5$. As a response to this unsettling result, Frisch (1933) suggested that the weighting system of the shocks was determined by the economic system, which therefore could be thought of as functioning as a propagation system.

The three disadvantages of Tinbergen's model meant that a new template had to be created. Tinbergen's old model was not able to redefine and solve these problems. Because these problems were themselves created by a changing vision of the business cycle and its generating mechanism, the new template would have to be coupled with a new conceptual vision that could accommodate this change. Interestingly, Slutzky was not the only economist in the 1920s to doubt whether the business cycle was a regular harmonic movement and wonder whether it might better be approached as a stochastic process. Irving Fisher (1925, p. 191; italics in original) even questioned the very existence of a business cycle:[6]

> Of course, if by the business cycle is meant merely the statistical fact that business does *fluctuate* above and below its average trend, there is no denying the existence of a cycle – and not only in business but in any statistical series whatsoever! If we draw any smooth curve to represent the general trend of population, the actual population figures must necessarily rise sometimes above and sometimes below this mean trend line.… In the same way weather conditions necessarily fluctuate about their own means; so does the luck at Monte Carlo. Must we then speak of 'the population cycle,' 'the weather cycle' and 'the Monte Carlo cycle'?

Fisher's considerations showed clearly that conceptual considerations about the general characteristics of cycles played a substantial role in deciding which template was best for explaining them. He argued that business fluctuations were not characterized by cyclical or regular patterns. He denied the possibility of tendencies toward regularity because "these tendencies may always be defeated in practice, or blurred beyond recognition" (p. 192). Drawing on analogical reasoning to specify his conceptual vision, a physical analogue to the business cycle for Fisher would have been

> the swaying of the trees or their branches. If, in the woods, we pull a twig and let it snap back, we set up a swaying movement back and forth. That is a real cycle, but if there is no further disturbance, the swaying soon ceases and the twig becomes motionless again. In actual experience, however, twigs or tree-tops seldom oscillate so regularly, even temporarily. They register, instead, chiefly the variations in wind

[6] Fisher's view was neglected at the time he wrote this, but it became representative of the view that has predominated since the 1980s.

> velocity. A steady wind may keep the tree for weeks at a time, leaning almost continuously in one direction and its natural tendency to swing back is thereby defeated or blurred. Its degree of bending simply varies with the wind. That is, the inherent pendulum tendency is ever being smothered. (Fisher 1925, p. 192)

Fisher's conceptual vision of the business cycle came closer to Slutzky's than Frisch's because the dynamics of the "rocking horse" or "pendulum" were "smothered" by the erratic behavior of the wind. However, Fisher was not the only economist who was struggling with what could be considered to be the best way of modeling the business cycle. As these considerations were closely connected to the choice of the most useful template, their views differed about what the best template was for modeling the business cycle.

In the decades that followed Frisch's contribution, economists increasingly argued that the economic system was not itself the mechanism that produced dynamic behavior such as a business cycle. According to them, the only dynamic it produced was stable growth. Because the economic system was believed to be a stable growth equilibrium system, the business cycle could only be the product of exogenous shocks. The random generator of shocks could be represented by a probability distribution, most often a Gaussian distribution, and hence the dynamic properties of the business cycle could best be represented by the moments of this distribution. It was a conceptual shift away from locating the dynamic properties within the economic system towards locating them outside the system, as external disturbances. This view resulted in dynamic stochastic general equilibrium (DSGE) models, first developed by Fynn Kydland and Edward Prescott (1982) in the early 1980s. When these DSGE models grew in dominance in the late 1980s and 1990s, the use of mixed difference-differential equations increasingly moved to the periphery of economics. However, the general procedure underlying the core of the original Tinbergenian methodology, solving a problem in a mathematical way by finding an appropriate mathematical model template that could capture all aspects of the conceptual vision, did not disappear.

This condensed case study modeling the business cycle with a sequence of templates shows how the choice of model template is closely tied to specific conceptual visions of general characteristics of target systems and how strongly visions determine which templates are accepted. Consequently, a shared conceptual vision partly explains the choice of one template over another in the history of business cycle analysis. However, it also shows that a new template does not easily replace a so far satisfactory template just because the conceptual vision has changed. In our case, the replacement of one model template by another did not immediately follow the changes in the conceptual vision of the business cycle. This is nicely expressed by Slutzky (1937, p. 105) in the opening paragraph of his 'Summation of Random Causes' article:

> Almost all of the phenomena of economic life, like many other processes, social, meteorological, and others, occur in sequences of rising and falling movements, like waves. Just as waves following each other on the sea do not repeat each other perfectly, so economic cycles never repeat earlier ones exactly either in duration or in amplitude. Nevertheless, in both cases, it is almost always possible to detect, even in the multitude of individual peculiarities of the phenomena, marks of certain approximate uniformities and regularities. The eye of the observer instinctively discovers on waves of a certain order other smaller waves, so that the idea of harmonic analysis, viz., that of the possibility of expressing the irregularities of the form and the spacing of the waves by means of the summation of regular sinusoidal fluctuations, presents itself to the mind almost spontaneously. If the results of the analysis happen sometimes not to be completely satisfactory, the discrepancies usually will be interpreted as casual deviations superposed on the regular waves.

The general patterns observed are thus based upon what the economic system is believed to be.[7] To model the business cycle, a mathematical template was needed that mathematically reproduced the conceptual vision of the general characteristics of the economy. When it was believed that the business cycle is endogenous, difference and differential equations were useful in building the business cycle models. When it was believed that the business cycle is exogenous, it was mathematically represented as a stochastic process.

4. Model Templates and Progress in Economics

Progress in economics is functional: a model can be used repeatedly as a template that is part of a common recipe to define and solve new problems. The notion of a model template is thus fruitful for thinking about progress in economics because it shows how common recipes that rely on models are reused in economics to define and solve diverse problems and therefore

[7] This is closely related to the idea that observation is theory-laden, defended for example by Norwood Russell Hanson's *Patterns of Discovery* (1958), which argues that one observes the world through the lens of theory.

how their reapplication leads to functional progress. We have also seen that the contribution of a model template to progress in economics depends crucially on a shared conceptual vision of the general characteristics of the phenomenon, such as the economic system, of which the business cycle is one particular element. In economics, progress through template use only occurs as long as this conceptual vision is shared and sustained.

That a template could only be reapplied as long as economists shared a conceptual vision about the business cycle becomes particularly clear when considering how the conceptual vision underlying Tinbergen's template changed within business cycle research. Mixed difference-differential equations ceased to be applied when economists changed their conceptual vision of the economic system from a cycle mechanism to an equilibrium system. In line with Knuuttila and Loettgers, our case study suggests that Humphreys's template view needs an important modification to explain the template's adoption and reapplication. A formal template can indeed be reapplied because it is in principle neutral to particular economic interpretations, but the application of a model template is not neutral; it is guided by a conceptual vision of the phenomenon to which the template is to be applied. Thus, the concept of a model template can capture the observation that models are reapplied only to those phenomena that share general characteristics. This is what makes a model template well-suited to study such phenomena. However, we have also noted that the mathematical structure in return can help shape the conceptual vision underlying the model template.

This is a different view of progress than Lucas's. Because Lukas argues that general theoretical ideas have for a few centuries and progress is mainly "technical," he observes a long history of continuous progress. Our contrasting view is that progress can be hampered by a change in the conceptual vision of the general characteristics of the phenomenon, in our case the economic system. The conceptual vision underlying a template presupposes a set of general characteristics of the target system. If the vision of the target system changes, it requires a different explanation and thus a different template to provide this explanation. A new model template will be chosen whose mathematical form and underlying conceptual vision can provide such an explanation.

Is a shared conceptual vision of the target system sufficient to explain the application of model templates? If so, progress in economics could be characterized as the reapplication of model templates. However, we have seen that the application of a template can also be explained by its strong initial influence the conceptual vision, by inducing a specific mathematical form. Tinbergen influenced the conceptualization of the business cycle in the 1930s by introducing a specific approach in which the business cycle was represented as generated by a mixed difference and differential equation. Another example is Slutzky's representation of the business cycle as a random walk. These were new conceptual considerations about the general characteristics of the phenomenon; new specific patterns or shapes of the phenomenon were formulated that changed conceptual visions. When adopted more widely, it enabled the application of that form as a template for new models. Thus, a template not only leads to progress because it helps define and solve new problems. It can also lead to progress because it mathematically co-creates the conceptual vision that makes it suitable for studying the phenomenon with these characteristics.

In the introduction to the special issue "Knowledge Transfer and Its Contexts," Herfeld and Chiara Lisciandra (2019, p. 6) add to the characterization of model transfer that "templates are particularly apt to be transferred to those domains that either a) share a similar methodology with the source domain or b) deal with problems that can in principle be tackled with that methodology." As our case study suggests, this is in part because a common recipe including a new model template and procedures for its creation can lead to functional progress. It was the introduction and acceptance of Tinbergen's methodology that allowed the business cycle to be modeled. This model template was then reapplied to various other problems in economics. Once the conceptual vision underlying the model template changed, the template was no longer considered useful.

5. Conclusions

In this chapter, we discussed a specific kind of progress in economics, progress involving the repeated use of mathematical models, which are part of the common recipes used in economics to define and solve new problems. We explicated such common recipes as including model templates, which are defined as mathematical structures that capture an underlying conceptual vision of the phenomenon's general characteristics. As such, these model templates are integrated combinations of conceptual visions of the phenomenon to be modelled and highly abstract mathematical forms that are needed for actually modeling them. We discussed the model template that Jan Tinbergen formulated to model the business cycle a specific case study of formulating and applying a model template, and we argued that functional progress in economics occurs when a shared conceptual vision of the phenomenon allows a model template to be reused to define and solve problems. Progress can be hampered when model templates are considered useless for specific problems, for which a change in the conceptual vision of the phenomenon can be responsible. However, functional progress can continue, once a new model template is developed and the conceptual vision underlying it is accepted.

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