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Science in Context / Volume 27 / Issue 04 / December 2014, pp 561 - 577
DOI: 10.1017/S0269889714000209, Published online: 13 November 2014

Science in Context **27**(4), 561–577 (2014). © Cambridge University Press 2014
doi:10.1017/S0269889714000209

Models at Work—Models in Decision Making

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1. The goal of this topical section

In recent years, research on modeling in both the philosophy of science and the social studies of science and technology has undergone an acute transformation. Philosophers and social scientists have begun to realize that science, in the words of Carrier and Nordmann, has increasingly shifted its focus from "epistemic or truth-oriented" research to "application-dominated" research. "Science is viewed today as an essentially practical endeavor" (Carrier and Nordmann 2011, 1) and should be considered in the context of its application. In accordance with this re-orienting of science, research on modeling has also changed. Still considering models as genuinely scientific tools, philosophers and social scientists promoted the "practice turn" that suggests a sharper focus on pragmatic issues and the performative and productive role of modeling. Application of models for the resolution of practice-related problems is viewed as an extension of science.

In this topical section, we highlight the next step of research on modeling aiming to contribute to the emerging literature that radically refrains from approaching modeling as a scientific endeavor. Modeling surpasses "doing science" because it is frequently incorporated into decision-making processes in politics and management, i.e., areas which are not solely epistemically oriented. We do not refer to the production of models in academia for abstract or imaginary applications in practical fields, but instead highlight the real entwinement of science and policy and the real erosion of their boundaries. Models in decision making – due to their strong entwinement with policy and management – are utilized differently than models in science; they are employed for different purposes and with different constraints. We claim that "being a part of decision-making" implies that models are elements of a very particular situation, in which knowledge about the present and the future is limited but dependence of decisions on the future is distinct. Emphasis on the future indicates that decisions

are made about actions that have severe and lasting consequences. In these specific situations, models enable not only the acquisition of knowledge (the primary goal of science) but also enable deciding upon actions that change the course of events. As a result, there are specific ways to construct effective models and justify their results. Although some studies have explored this topic, our understanding of how models contribute to decision making outside of science remains fragmentary. This topical section aims to fill this gap in research and formulate an agenda for additional and more systematic investigations in the field.

2. The need to extend the practice-oriented approach to modeling

Developing our concept of modeling in decision making, we follow up on the practice-oriented approach that has been envisaged in the philosophy of science and in the social studies of science and technology during the last 20 years. Significant efforts have been placed on resolving the proposed "puzzle of representation" and related idealization issues: "How can [models] represent, if they, well, misrepresent?" (Callender and Cohen 2006, 72). These efforts resulted in the shift toward an increasing concentration on the concrete functioning of models and on modeling practices (Knuuttila et al. 2006). This practice-oriented approach is related to a stronger focus on the pragmatic aspects of model use (Suárez 2003 and 2004; Giere 2004; Knuuttila 2005 and 2011; Alexandrova 2008; Mäki 2009) in the performative idiom (Pickering 1995; Callon 1998; MacKenzie 2006 and 2007) and the productive account of models (Knuuttila and Merz 2009). The related concepts in philosophy of science and social studies of science are "epistemic cultures" (Knorr Cetina 1999 and 2007), "epistemic lifestyles" (Shackley 2001), models as "epistemic artifacts" (Knuuttila 2011), models as "mediators" (Morgan and Morrison 1999), and models as "boundary objects" (Star and Griesemer 1989).

The "practice turn" contests the understanding of models as purely representational structures (Knuuttila 2005 and 2011). Models are epistemic artifacts or tools that are *made* productive by means of human intervention and manipulation within particular scientific practices. The definition of models as epistemic tools postulates them as material objects that are not "ready-made" but unfolding elements of situational practices (Knuuttila and Merz 2009; Knorr Cetina 1997 and 2001; Rheinberger 1997). The centrality of these unfolding processes requires explicit tracing of the biographies of the models (Knuuttila et al. 2006).

The practice-oriented debate furthermore generates an increased focus on the *pragmatic* aspects of models, which helps to explain why models are *useful* tools despite their generic character, inaccuracy, and tenuous connections with the real world (Morgan and Morrison 1999; Mäki 2009). In this literature, consideration is given not only to models (their structure, methods, and forms of idealization) but also to modeling *practices* and their *contexts*. To comprehend the nature of models, it is here argued, one should consider the analysis of additional factors, such as the roles of model

users and their prospective purposes, as well as the importance of internal and external audiences, processes of judgment, justification, and negotiation.

Although we take the practice-oriented approach as characterized above as our point of departure, we observe that this concept has been developed by paying attention to scientific inquiry only. Here, modeling remains primarily a scientific practice and models and simulations are considered as "machineries of knowledge construction" (Knorr 2007) or "epistemic tools" (Knuuttila 2011).

Novel applications of models in policy and business have transcended the understanding of models as "epistemic tools," however. Recent literature on models for decision making highlights their new roles in politics and management (Jasanoff 1990 and 2005; Shackley 1998; Den Butter and Morgan 2000; van Egmond and Zeiss 2010), e.g., in economic policy (Evans 1999; van den Bogaard 1999), climate policy (Shackley et al. 1999; Shackley 2001; Petersen 2008; Gramelsberger 2011; Gramelsberger and Feichter 2011), flood risk management (Lane et al. 2011), financial markets (MacKenzie 2003 and 2006; Beunza and Stark 2012), and health-care policy (Mansnerus 2012).

These studies emphasize that the traditional separation of science – as a place of model construction and development – from the realm of pragmatic model application by practitioners has lessened. Many models are no longer created in the "ivory tower" of science and then transferred as fixed objects to practical fields in which they are mechanically applied. Rather, recent research on modeling demonstrates that, in many cases, the "scientific life" of models cannot be separated from their "working life" (the term of Erika Mansnerus) external to science: scientific and practical criteria and interests are intertwined. This means that scientific aspects may derive from this "working life" or that non-scientific fields – through their involvement in the creation and application of models – become grounded in scientific modeling. As a result, models influence political and economic decisions. In some cases, models are created directly in the field of application, for example, in quantitative finance. Thus, we refer to the true entwinement processes, the "politics of knowledge" (Landström and Whatmore in this issue), instead of an "extension of science."

Decision making is a process in which the real entwinement of politics/economy and modeling is typically evident. Thus, the practice-oriented approach should be further developed and amended to focus on the development of models and their use within specific decision-making situations, in which epistemic *and* non-epistemic aspects of modeling are interwoven. In our theorizing about models, we have to take the next step toward understanding how models structure decisions and actions and the different roles they occupy in these processes. Although the philosophy of science and the social studies of science have revealed important insights in this area, they are not detached from the science-focused understanding of modeling, and their results remain fragmentary.

To illustrate the rather fragmentary and inaccurate nature of studies of modeling in decision making, we observe that some case studies focus on *singular aspects* of model construction for decision making and model use in decision making. The majority of these studies concentrate on model-based *knowledge production* without providing

any concrete insight of how the outcomes of models translate into political decisions (e.g., Shackley et al. 1999). Of the studies on model use that do explain how model outcomes are incorporated into decisions, scholars neglect the origins of models; here, the models are simply "given" and, thus, are rather passive (e.g., studies on model use in risk management in banks by Mikes 2009 and 2011 and in the practice of derivatives trading in financial markets by Beunza and Stark 2012).

The aforementioned studies typically provide an extensive list of the various functions that models in decision-making practices may have. Investigations of the functional roles of models are a part of the practical turn in that they demonstrate that models do more than inform or provide knowledge and pragmatic aspects are particularly crucial for understanding how models function. All three articles in this topical section contribute to ongoing investigations of the extensive roles of models: Models enable the dissemination and democratization of evidence (Landström and Whatmore in this section) and the coordination of activities with reference to "boundary objects" (van Egmond and Zeiss in this section); they can be used as communication, argumentation, and negotiation tools that provide "discursive spaces" (Evans 1999 and 2000) in which shared understandings are established (Landström and Whatmore in this section). Models also organize and rationalize the forecasting process, facilitate consistency in forecasting, provide a framework in which the market situation is defined, or are anchors for the development of a consistent story, e.g., the view on the market (Wansleben in this section). Furthermore, models function as "bridges" between disciplinary scientific communities and teams of practitioners (van Egmond and Zeiss in this section with reference to Evans 2000). They are also crucial for legitimizing and justifying decisions (van Egmond and Zeiss in this section).

At the same time, the description of the extensive roles of models in various heterogeneous fields provides vague indications about the mechanism of model participation in decision making. It is our contention that this occurs because research on modeling has traditionally focused on science. However, to understand how models work as decision-making tools, we have to begin with the decision-making process in which models are involved. In descriptions of the role of models in decision making, the definition of decision making is typically assumed to be known or given. However, this assumption is not trivial if we consider the variety of existing decision-making concepts. Should we subscribe to rational choice as a still dominating approach which presupposes the exact calculation of an optimal action? Or is "bounded rationality," or any other normative or cognitive decision-making concept more suitable? Thus, to deliberate meaningfully the role of models in decision making, we – maybe paradoxically – have to temporarily disregard a model-centered discussion and focus on the conceptualization of the decision-making process. In analyzing the entwinement of knowledge and policy, we deem it necessary to consider not only *modeling practices* but also *decision-making practices.*

Hence, prior to further developing the discussion on models in decision making, it is crucial to clarify our understanding of decision-making situations.

3. The major features of decision-making situations compared with the basic situation in science

Based on the analysis of the contributions to this special section and the related literature, we refer to the American pragmatist philosopher John Dewey and define a decision-making situation as an "incomplete situation":

> This incompleteness is not psychical. Something is 'there', but what is there does not constitute the entire objective situation. As there, it requires something else. Only after this something else has been supplied will the given coincide with the full subject-matter. This consideration has an important bearing upon the conception of indeterminate and contingent. . . . The logical implication is that of a subject-matter as yet undeterminated, unfinished or not wholly given. The implication is of future things. (Dewey 1915, 506)

Goffman uses the term "problematic situation" to denote "something not yet determined but about to be" (Goffman 1969, 110). The genuine uncertainty of the becoming situation and, thus, the principal unawareness of what is going to happen are the major characteristics of the decision-making situation in all three contributions to this special section.

Because the decision-making situation is constantly *becoming,* some information is not always available at the time of decision making and cannot be searched, obtained, or processed in principle. In the situation of radical uncertainty and undecidability, true decisions always exceed "the calculable programme" (Derrida 2001); they elude calculation rules or other types of rules. Agents *have to decide* in an incomplete situation, although the reasons and rules for doing so are fragmentary and insufficient.

Agents *have to decide* because decision-making situations demand actions; those actions have severe and lasting consequences in the future. Agents cannot allow themselves to stay passive or be paralyzed by the described contingencies: they have to make decisions and act to alter existing conditions:

> But it is the given of something to be done. The survey and inventory of present conditions (of facts) are not something complete in themselves; they exist for the sake of an intelligent determination of what is to be done, of what is required to complete the given. . . . The discovery that a man is suffering from an illness is not a discovery that he must suffer, or that the consequent course of events is determined by his illness; it is the indication of a needed and of a possible mode of action by which to restore health. (Dewey 1915, 508)

Keynes, for example, also states that – although the economic world is genuinely uncertain – "the necessity to action and for decision compels us as practical men to do our best to overlook this awkward fact" in order to make decisions and intervene in reality (Keynes 1937/1973, 213f.). The necessity of intervention makes the required

decisions and actions fateful (Goffman 1969; Knorr Cetina 2009); agents know there is a lot at stake (Dewey 1915, 507; Alexandrova 2008).

As opposed to "killed moments" (such as "thumbing through a magazine") or the routine of everyday life, a fateful activity of gambling, for example, is consequential because it has "the capacity . . . to flow beyond the bounds of the occasion in which it is delivered and to influence objectively the later life [of the bettor]" (Goffman 1969, 116). The notion of situational becoming is formed: "In offering this definition Goffman of course knew, but did not emphasize, that expected consequences also objectively influence how the situation itself proceeds – for example, the dread of losing may contribute to the thrill of gambling" (Knorr Cetina 2009, 81).

In the contributions of this topical section, flood management, pesticide emission assessment, ecology, health care policy, and financial markets provide valuable examples of fields in which decisions are genuinely fateful. Furthermore, fatefulness causes the issues of legitimization and acceptance of model-based decisions to be especially prominent: there is a need to justify model results and related decisions to a much broader audience than in the field of science. Fatefulness also frequently involves a particular time pressure – to decide immediately – which science does not imply to such an extent. To decide and act in a becoming world, agents strive to resolve the genuinely incomplete situation. Closure makes the uncertain situation manageable and decidable. It is about the "choice of the framework in which [questions] are asked and . . . the choice of the rules used to connect what we label 'the question' with what we take for an 'answer'" (von Foerster 2003, 293). The centrality of the closure process implies the departure from the still widely accepted understanding of decision making as a purely analytical calculation and mechanistic choice.

Alternative ways are necessary to address the uncertain, fluid, and becoming economic situation. To date, some relevant concepts have been developed: the "practical judgment" (Dewey 1915), the "successive limited comparison" or "muddling-through" (Lindblom 1959), the process of "calculating where we can" (Keynes 1936/2012), "framing" (Goffman 1974), "heuristics" (Gigerenzer and Todd 1999; Gigerenzer 2007), "bricolage" (de Certeau 1984), "mindfulness" and "sense-making" (Weick 1995 and 2001; Weick and Sutcliffe 2001), as well as "acting sensibly" (Smith 2011). All of these decision-making concepts differ from the calculation-based techniques of decision making as presupposed by the rational choice theory, for example. These authors acknowledge that it is impossible to perfectly eliminate uncertainty and lack of knowledge and are characterized by simultaneously acting toward many objectives, monitoring the constantly changing environments, identifying and juggling rules that are constantly adjusted, discovering the way *en route* and maintaining an escape path. There is considerable "preparatory work and the work of seeing and attention" (Knorr Cetina 2009, 76) necessary. While determining the route in the process of deciding and acting, they may rely on the wrong map and succeed (recall Weick's example of the lost alpinist group in the Alps, who rescued themselves after one of the members located the map of Pyrenees; this wrong map helped the group

to become active alert and rescue itself). We refer to *action-like decision-making* (Goffman 1969), which enables coping with the genuine uncertainty and undecidability in an incomplete situation by actually dealing with the world.

The decision-making process can be conceptualized as Dewey's "practical judgment," which is the process of constantly searching for fateful solutions and actions. "Practical judgment" – as opposed to epistemic judgment – indicates not only the discovery of fixed foundations of knowledge and expertise, which is typical in science, but first of all the directed process of provisional "fixing upon the course of action demanded to carry an incomplete situation to its fulfillment" (ibid., 514). It requires the combination of some formal rules with intuition, interpretation, "preparedness" (Knorr 2009) and creativity (Joas 1996). This understanding is consistent with the findings of the contributions in this section.

Those insights with respect to the decision-making process require additional analyses regarding the conceptualization of models, i.e., our understanding of what models are and how they work as elements of decision making in policy and economy. Certainly, we can extract important ideas from the "practice turn" literature to stress the flexibility of models, their materiality, the variety of their roles, and the importance of pragmatic factors for their use. However, decision making imposes conditions that we do not frequently encounter in science such as: time pressure, the necessity to act, the fatefulness and immediacy of decisions, and the high demand for legitimization and justification. These conditions distinguish the construction and use of models in decision making from dealing with models in science so that the extended account of modeling becomes necessary. In the contributions to this topical section, we discover some components of this extended conceptualization.

4. Models in Decision-Making

4.1 Decision-making at large

As previously mentioned, the primary drawback to existing studies on models in decision making is their fragmentary character, i.e., they focus on only one aspect, such as model construction with a strong emphasis on epistemic work or heterogeneous model roles in decision making. However, the concept of decision making as "practical judgment," as constant search for solutions under conditions of uncertainty and necessity to act as well as to justify decisions, necessitates the investigation of decision making *at large* (van Egmond and Zeiss in this section). This understanding is programmatic. Decision making does not occur at a particular point in time. It is a process that includes the (policy) initiation demand for the development of a model, the process of model construction, and the subsequent application of the evidence and predictions of a model for intervention and action (fig. 1).

The concept of decision making *at large* implies that fateful political decisions are not made after a model is constructed and becomes available as a completed calculative tool.

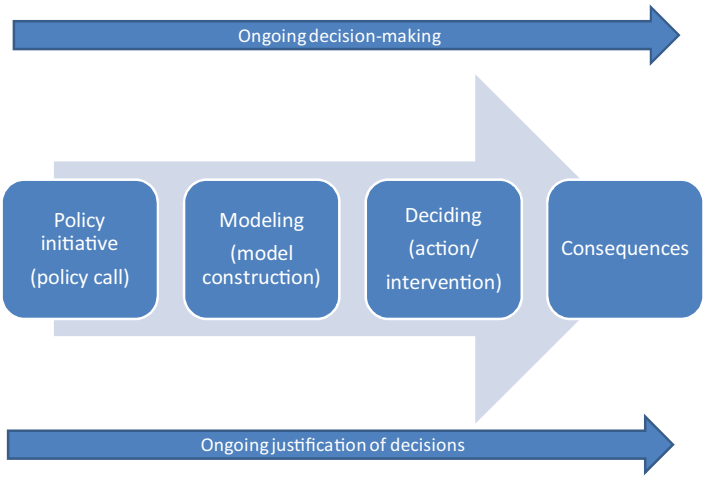

Fig. 1. Decision making *at large*.

Rather, model-based political and economic decisions *include* the initial call for a model and the phase of model construction. During the stage of model initiation, political requirements are translated into scientific possibilities, which significantly determine questions that are later raised and answered by the model. Van Egmond and Zeiss (this section) explain:

> During the construction phase of models, models offer space for coordination and negotiation between different research organizations and science and policy domains. They thereby bring together different social worlds, and legitimate participation in (new) policy fields. This may result in broad(er) support for the decisions made, contribute to a depoliticization of political issues, or even create "new" policy fields (health economics). Moreover, models become a common reference point and/or an obligatory point of passage for the policy field. Model construction can therefore be considered as an early phase of decision-making processes, intended as such or not. During this stage, decisions are made by both scientists and policy makers, which influence the later model outcomes, i.e. science-policy boundary work takes place, and insiders and outsiders are created.

The provisional "fixing upon the course of action" (Dewey 1915, 514) begins while *the model is not yet here but just about to be*. For example, arguments for legitimization and justification of future model-based decisions commence in this early stage and determine the subsequent uses of the models.

4.2 The phase of model construction

The contribution by Landström and Whatmore in this section provides valuable descriptions of three modes of model construction and illustrates the importance of this decision-making phase for the "working life" of models. The authors contrast

the purely scientific *mathematical experimentation* with the pragmatic modes of *virtual engineering* and *participatory modeling* in flood management in the UK. Academic scientists are exposed to practically no constraints during model construction, whereas engineering consultants, for example, rely on pre-existing models, standardized software, and visualization tools that conform to the needs of clients. The authority to develop new tools and ask new questions is often as important as the effort to create the best possible model. This (often standardized) process of model construction predetermines subsequent approaches to situation closure and "constrains which questions can be asked and answered" (Landström and Whatmore in this section).

Of particular interest is the use of participatory modeling as a way of formally including lay citizens into decision-making processes at an early stage. In this special section, Landström and Whatmore, as well as van Egmond and Zeiss, describe how models facilitate this inclusion – science steps outside of its traditional institutional network and involves various stakeholders in the process of knowledge generation using computer models. For example, scientists develop scenarios, which are the bases for computer simulations, in collaboration with local communities. Thus, knowledge generated by models takes a genuinely interactional form; it is about the collective development of knowledge *with* science rather than *in* science: "Participatory modeling brings to the forefront the *politics of knowledge*" (Landström and Whatmore in this section; our emphasis) because in these processes knowledge that is relevant for later fateful decisions is produced; it feeds them.

However, participatory modeling as a "shared activity" in the stage of construction often remains inconsequential. In this topical section, van Egmond and Zeiss discuss an interesting case of the LARCH biodiversity assessment model in which participation of non-scientists (namely, policy-makers) failed due to the lack of interest and motivation by the latter to contribute. Moreover, Landström and Whatmore's article indicates that the democratized expertise of models does not imply an ultimate inclusion of local participants into formal decision making (these findings are consistent with existing social research on participation, [e.g., Jasanoff 2003; Lengwiler 2008]). However, the concept of decision-making *at large* and its focus on model construction as an early phase of decision making stresses the potential for participatory modeling as a way to influence decisions, which is often wasted or not recognized.

The importance of the model construction phase for the determination of subsequent interventions and actions can also be tracked in the article by van Egmond and Zeiss (this section). For example, the PEARL model on pesticide leaching was originally designed to be a high-quality, authoritative, and broadly accepted model in the European community; the issue of legitimization was crucial from the inception of the model. These particular policy aims and their consequential pursuit determined at the very early stage of the model's "working life" that the PEARL model "became an obligatory regulatory instrument in assessing which pesticides can enter the market and which cannot," i.e., "an obligatory regulatory point of passage" (van Egmond and Zeiss 2010). At the same time, van Egmond and Zeiss depict the development of the Care

model, which assesses economic issues of the Dutch health care sector, as the process in which political arguments are substantially intertwined with scientific considerations. Thus, the scientific soundness and pragmatic arguments of usefulness for policy collided and, in the end, political interests dominated and impeded the creation of an efficient model; this development determined subsequent ways of model use as a very tentative, sporadically applied instrument.

> To understand the role of these models in decision making processes, we argue that these models should be addressed in the context of what we call "policy and decision making at large." We put forward the argument that it is crucial to consider model construction as an early phase of decision making which, in turn, is mediated by the changing contexts within which the models are further developed and operate. (van Egmond and Zeiss in this section)

In the next section, we address the issue of the ever-changing contexts in which decision making occurs, as well as the related consequences for our concept of models as decision-making instruments.

4.3 Decision making as a high-context activity

If we subscribe to the understanding of decision-making as "practical judgment," the aforementioned *model-focused view*, which has dominated discussions about model use in applied fields thus far, should be considered problematic. It seems contradictory to conceptualize a model as a *central* instrument of decision making for two reasons.

First, models – due to their nature – are calculative instruments; their role as "devices of calculation" (Wansleben in this section) cannot be completely eliminated by other roles. However, as previously discussed, calculation of any type is inadequate to reach a decision; every calculation should be subverted, exceeded, and complemented by other "instruments," such as intuition and judgment. Thus, it is inconsequential (incoherent) to proclaim models as the principal tools of decision making. Second, in the ever-changing context of "practical judgment," a specific temporal ordering of model-based decision making becomes obvious: Models are more rigid and fixed than the fluid decision-making situation. Thus, they will always remain a part of the constantly incomplete knowledge about this situation and may help to reduce uncertainty and close the situation only to the extent that decisions become possible (but not optimal or unambiguous).

How can such an insufficient instrument be employed to make decisions? To become useful for decision making, models as abstract and idealized instruments should be connected to the real world – they should be de-idealized – in a particular way. Due to the substantial context, the ongoing perfect adjustment of a model to a world that constantly changes would be a hopeless endeavor. Thus, in contrast to the existing

philosophical accounts in which the de-idealization of models typically presupposes the manipulation of the model itself (e.g., the replacement of unrealistic assumptions or the re-introduction of omitted factors (Cartwright 1989; Nowak 1980 and 1989; Hausman 1992; and McMullin 1985), the connection of models to the real world of decision making does not require the constant changing of models (Mackett 1998; Svetlova 2012 and 2013).

Admittedly, the contributions to this topical section demonstrate that models can be adjusted in the process of their use. For example, van Egmond and Zeiss state that the PEARL model is regularly updated "when new knowledge becomes available or solutions are found for problems that had been identified." This adjustment occurs, however, in retrospect, after the world has already changed. Note that our claim is not that models remain stable after their construction is finalized but that the speed of the ongoing adjustments of models is much slower than the change of the natural environment or market reality. Wansleben (this section) also emphasizes that models rely on the inertia between past and future and the presupposition of stable relationships between variables. Furthermore, some pragmatic factors contribute to the relative stability of models. Thus, van Egmond and Zeiss (this section) suggest that a number of sub-versions (modules) of the LARCH model were developed to enable the application of the model in ad-hoc projects; however, the modules remained fixed after this adjustment due to cost and time constraints.

Paradoxically, the relative fixity of models enables their successful use as an effective navigating tool in a complex and ever-changing reality (Svetlova 2013). Maintaining stability of the model enables users to observe the becoming world and orientate themselves in it (otherwise, they would resemble a captain who tries to navigate a ship by using different binoculars every time or by constantly moving the binoculars). Models in decision making do not help to "represent" or to "catch" reality. They provide a structure for analysis and discussion and serve as anchors or benchmarks to which a changing reality is subsequently compared and, thus, can be observed (models as "spectacles" in Wansleben's contribution). In the process of decision making as "practical judgment," models do not radically reduce uncertainty and close the situation by providing alternatives and calculating the optimal solutions; they primarily participate in the "preparatory work and the work of seeing and attention" (Knorr Cetina 2009, 76). Wansleben (this section) illustrates this point by describing how foreign exchange analysts use models as anchors for stories ("views") about future market development. These investment professionals do not blindly accept the model result as an ultimate forecast but enhance it by asking "What does the model tell us within this particular situation?" By answering this question, analysts compare the model and the real world and incorporate pragmatic aspects of decision making, such as intuition, judgment, audience, and justification, which complement the formal results of the model and make even the "untrue" (imperfect) model useful (recall the "wrong" map of Pyrenees).

Note that models play an active, although highly mediated, role in decision making. Their genuinely calculative nature and relative rigidity cause them to assume secondary

roles (communication, mediation, and justification) in deciding and determine the necessity of active mediation between models and reality (models as "entangled instruments" in Wansleben's article). For example, in applied contexts, such as in business, "the model is an aid to appraisal and thus decision-making, but is far from being the prime focus for the decision-maker" (Shackley 1998, 86). In the process of making models work in decision making, pragmatic factors such as the active roles of model users, the audience, and narrative devices become especially crucial. Note that these factors are not actual parts of the model structure despite their relation to it, however. Pragmatic adjustments work "outside" of the model and enable the explicit connection of models to the world. Thus, the concept of decision-making *at large* exhibits not just a temporal dimension: Only by analyzing the entire process of the pragmatic de-idealizing efforts, can we understand how models reduce uncertainty and enable decisions in the highly contextual fields of their application. These considerations explain why investigations of "models at work" should focus on the decision-making process *at large* and not just on modeling issues.

4.4 Model-based lifestyles in decision making

The described processes of model adjustment and de-idealization are significant and can assume different forms, depending on how they proceed, various decision-making lifestyles, or "cultures of modeling and model use" (Wansleben in this section).

First, they are characterized by the grade of reliance on the model by users, or the formal status of the model in decision-making. The existing literature as well as contributions included in this topical section discuss a range of possible lifestyles: from the "over-calculative view" and "quantitative enthusiasm," which are characterized by the strong reliance on models in decision-making, to the "under-calculative view" and "quantitative skepticism" as cultures, in which models are used tentatively and can always be abandoned in favor of some pragmatic deliberations, such as orientation towards peers/competitors or judgment (Beunza and Stark 2010; Mikes 2009 and 2011).

In the contributions to this section, such polar positions can also be found. On the one hand, the "quantitative enthusiasm" is represented by the PEARL model, which is a standard obligatory model to assess pesticide leaching and to evaluate related policies. The "quantitative skepticism," on the other hand, which is not officially employed to assess biodiversity and whose role in the decision-making process is nearly impossible to trace, is illustrated by the culture of model neglect in the field of financial analysis (models provide "a piece of knowledge that is not at the center of their [analysts'] own knowledge culture") in the Wansleben's contribution as well as the LARCH model in van Egmond and Zeiss' article.

We find various gradations between these polar positions. For example, the Care model, which is "a distribution model" that enables politicians "to think and to talk

about healthcare in terms of markets and competition," influences the direction of policy and decisions but does it in a strongly mediated and indirect way (van Egmond and Zeiss in this section).

How models influence decision making is also highly determined by the organizational settings in which the models are applied. Decision-making lifestyles depend on organizational framings that determine whether the model users are obliged to strictly implement the results of the model or whether they enjoy flexibility, i.e., whether the style of model use represents one of the poles of the aforementioned range (Svetlova 2008 and 2012; on the importance of institutional settings for model use, see also Greenberger et al. 1976; Smith 1998; Mikes 2009 and 2011). Wansleben (this section) also describes how the affiliation of bank economists and analysts with particular organizational departments affects their ongoing work on models as well as the status of models in their "culture of modeling and model use."

The organizational aspect is also crucial because models travel not only through time – among various stages of decision-making *at large* – as depicted in fig. 1, but also through organizational parts and cultures of model use and decision-making lifestyles. This notion is addressed in the contributions of Wansleben and van Egmond and Zeiss. While traveling, models change their roles and statuses; thus, the investigation of models' traveling routes becomes particularly important. All these observations have consequences for further research.

5. A case for a more elaborated biographical approach

The concept of decision making *at large* as a process that simultaneously includes preparatory work, model construction, and model use stresses the centrality of a biographical approach for understanding the roles of models in decision making. Until now, the common denominator of this approach (Appadurai 1986 or 1990; Rheinberger 1997; Daston 2000; Howlett and Morgan 2011) was an interest in tracing the circulation of epistemic things and ideas across various, primarily scientific, contexts and uses. However, the consideration of models in the framework of decision making *at large* requires the expansion of the biographical approach because models distinctly transgress their common understanding as epistemic objects.

In this context, the investigation of the traveling routes of models becomes pivotal. Models may be developed in fundamental science and subsequently travel to the field of their application in policy or financial markets while undergoing severe changes in the course of this process; or they may be constructed in the practical field and subsequently travel to fundamental science for further development. In addition, models travel between and within organizations and change their roles and status. It is important to follow model traveling routes "over long periods of time" (van Egmond and Zeiss in this section) without focusing on either model construction or model use. Researchers should care about description of decision-making as a coherent process (as represented

in fig. 1) from the idea of a new model or a political demand for it to the justification of model-based decisions and their consequences. In this respect, we consider van Egmond and Zeiss' paper (this section) a trendsetter.

In long-term studies, detailed descriptions of how model results are translated into political and managerial decisions should be provided. We did not find such descriptions in the existing literature nor were they the focus of the contributions in this topical section. However, it is crucial to obtain more "messy" details on, for example, how the EUR/USD forecast of the Forex models is translated into a decision to buy or to sell a particular amount of a particular currency, or how the results of the Care model are used to make concrete decisions about healthcare policy. Generally, it is important to investigate the decisions that can and cannot be made with models. Furthermore, a detailed analysis of how model-based decisions are justified, which is also largely overlooked, is needed.

Moreover, a more detailed classification of decision-making lifestyles and cultures is required. In this article, we presented a range of extreme lifestyles: from the trust in and reliance on models to the inattention to models. However, in most cases, it would be helpful to classify models according to parameters, such as personal trust in models by users, organizational requirements (to blindly follow or overrule a model), the role of the external audience and its expectations, typical narratives, and methods of model de-idealization. The compilation of a grid that comprises major criteria for further research of decision-making cultures would be particularly helpful in comparing future case studies.

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