Chapter 17: Model Transfer in Science

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Penultimate version

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Abstract
A conspicuous feature of contemporary modelling practices is the use of the same mathematical forms and modelling methods across different scientific domains. This model transfer raises many philosophical questions concerning, for example, the exact object of transfer, the relationship between the model and the target domain, the specific challenges such transfer confronts, and the ways in which model transfer relates to scientific progress. While the interest in studying model transfer has increased among philosophers of science in recent years, the phenomenon has not yet received its due attention. The literature is scattered and much of it has addressed questions around the factors that might explain model transfer, such as whether the different target phenomena to which a model is applied eventually prove to be structurally and dynamically similar, or whether they have to share more fundamental ontological features that explain the interdisciplinary success of distinct models. This chapter surveys the existing literature on model transfer with the main goal of highlighting the main findings of existing discussions and pointing out open issues whose discussion would improve our understanding of this highly relevant phenomenon in science.

1. Introduction

Scientific research is characterized by strong disciplinary specialization that often manifests in highly abstract models tailored to particular target systems. At the same time, a pertinent feature of contemporary science is that there is increasing interaction across different fields or even disciplines. One way this interaction manifests is in an intensified transfer of models across domains. For instance, the well-known Lotka-Volterra model has not only been used to explain predator-prey interactions in population biology, but has also been transferred into medicine and economics to study phenomena as disparate as the growth of cancer cells and the business cycle (for an historical account, see Knuuttila and Loettgers 2017). Modern science is full of examples of such model transfer. This transfer can be successful but might also confront severe challenges and can even sometimes fail. Beyond its pertinence in scientific practice, model transfer can also have critical functions, such as potentially serving as a catalyst for scientific progress and a driver of innovation (e.g., Boumans and Herfeld 2023; Price 2020).

Although model transfer has recently gained more attention in philosophy of science (e.g., Bokulich 2015; Donhauser and Shaw 2019; Grüne-Yanoff 2011; Herfeld and Lisciandra 2019; Houkes and Zwart 2019; Humphreys 2019; Knuuttila and Loettgers 2014; 2016; Knuuttila and García-Deister 2019; Lin 2022; Marchionni 2013; Price 2018: 2020; Zuchowski 2019), the phenomenon has not yet been extensively studied by philosophers of scientific modelling. There is an expansive literature that has studied the cross-domain transfer of a variety of epistemic objects and what could be considered to belong to the category of knowledge generally. It concerns the circulation of knowledge (e.g., Ash 2006; Herfeld and Lisciandra 2019; Howlett and Morgan 2011; Lipphardt and Ludwig 2011; Kaiser

1998; Nersessian 2002), the nature of interdisciplinarity, the transfer of facts, and the travel journeys of data (e.g., Andersen 2016; Howlett and Morgan 2011; Leonelli and Tempini 2020; Mäki et al. 2019). While this literature proves instructive in locating the phenomenon of model transfer in the scholarly landscape, it has not straightforwardly been concerned with model transfer itself. Rather, the debate on model transfer is still in its early stages.

The main goal of this chapter is, therefore, to systematically survey the existing literature on model transfer, thereby pointing to possible routes for future research. The review is structured around three kinds of closely connected questions that have been addressed so far. The first question is how we can conceptually think of those models that are transferred, asking for a proper account of the unit of analysis for such transfer. The second question is why some models are transferable across domains to address often fundamentally distinct problems, asking for an explanation of model transfer. The third set of questions is whether and in which way the practice of model transfer can contribute to scientific progress.

2. Approaches to Model Transfer

Most of the existing literature has focused on the question of why models are transferrable across domains. The question is, when we take specialized models as representations of some target system, how can the same model provide insights about fundamentally distinct systems from different domains? Most philosophers have sought the answer by asking whether the object of transfer has specific characteristics that allow for its transfer; in other words, they have provided an answer to the question of what exactly the object of transfer is. However, there is neither agreement about the exact object of transfer nor, more importantly, about the core characteristics that enable or prevent cross-domain model transfer. Some philosophers argue that the generality, tractability, and flexibility of models explain their transfer (Humphreys 2002; 2004). Others argue that conceptual features and their justification – in addition – make the model attractive for using them in other domains (Knuuttila and Loettgers 2014; 2016).

Many philosophers either defend an analogy-based or a template-based approach to thinking about the unit of transfer. An analogy-based approach refers to analogical reasoning as a cognitive or research strategy that allows for using concepts, models, or methods that are familiar in one domain in one in which they are less familiar. They do so by positing shared features of the respective phenomena (or some theoretical descriptions of them) in both domains and/or similarities of the models used in both domains to study phenomena (e.g., Hesse 1963; 2017). What explains the transfer of concepts, formal structures, and methods across domains is this similarity relation either between two target systems or between the models of both target domains. On this view, positing such material or formal relations licenses inferences from a system in the source domain to a system in the target domain, or inferences from one model used to theorize about a target system in the source domain to a model used to theorize about a target system in a new target domain (e.g., Hesse 2017; Knuuttila and Loettgers 2016; Bokulich 2015; Zuchowksi 2019).

Jhun et al. (2018) provide an analysis of the Johansen–Ledoit–Sornette (JLS) model of critical market crashes from econophysics in light of proclaimed analogies between critical phase transitions in statistical physics and stock market crashes. While they show the limitations of this analogy in enabling the unconstrained use of common explanatory strategies from physics in economics, they argue that the JLS model is useful in that it can offer different kinds of explanations of and theoretically describe stock market crashes as critical phenomena analogous to critical phase transitions of physical phenomena. Generally, relying on analogical inference in explaining model transfer implies a commitment to the view that models represent their target system not by correspondence or isomorphism but by analogy (e.g., Hesse 2017, 305). On this view, the justification of predictions from transferred models about new target systems – potentially in different domains – becomes a matter of the strength of analogous argument (see entry on analogies and metaphors in this Handbook).

The template-based accounts originate in Paul Humphreys' suggestion that contemporary computational science is organized around a limited number of computational templates for the use of which explicit assumptions can often be formulated (Humphreys 2002; 2004). As such, the decision of whether such templates can be transferred across domains does not have to rely on vague or implicit similarities between phenomena. Templates are general, representational devices that ground the construction of computational models. On this view, what is thus transferred across domains is not the model itself, but the template that a model can be built on. Such templates are more easily transferred than most models because they are based on mathematical or computational forms and methods that are flexible enough to study a variety of different problems in distinct domains (Humphreys 2002; 2004; 2019). Different kinds of templates differ on various levels with respect to their degree of abstractness, their relation to an existing scientific theory, and the degree to which they were originally developed for a specific target system, etc. Examples are the Poisson distribution from probability theory, mathematical models from game theory, the Ising and the Lotka-Volterra models, Newton's second law, or the Barabási-Albert preferential attachment model of network formation. Albeit to different degrees, those templates have in common that they – apart from being abstract - are general and as such subject-independent, which is why they are highly flexible and applicable to fundamentally different target systems. Besides their generality, a second distinguishing feature is their tractability. While some templates are mathematically tractable, most templates become computationally tractable when turned into computational models. Both features explain why templates are transferrable across domains.

In addressing model and template transfer, Humphreys introduces a notion of a formal template contrasting it to theoretical templates. He defines a theoretical template as:

> a general representational device occurring within a theory, containing at least one schematic, second order, property variable (where a second order variable is one that has n-ary predicates as substitution instances) and is such that, when all of the schematic variables have been substituted for, can be successfully used to represent a variety of different phenomena within the domain of that theory (Humphreys 2019, 3)

So defined, theoretical templates are to some degree domain specific. To turn them into computational templates, they go through a construction process in which they are complemented by construction assumptions and a correction set. The resulting computational template becomes complemented by an interpretation and an output representation to turn it into a computational model that is ready to be applied to some target system. While a concrete ontology is only specified in the construction process, theoretical templates usually originate in some interpreted scientific theory and are, as such, accompanied by a physical interpretation that constrains them. A theoretical template is, as such, often considered to be part of the fundamental principles of this theory (Humphreys 2019, 3). This is why the domain of application of theoretical templates – before and after its transfer – can be constrained in parts by the scientific theory the template is derived from.

This last characteristic is what mainly differentiates theoretical from formal templates. Although formal templates are applied to a variety of different systems, they constitute at first instance purely mathematical objects that are either independent or that have been fully separated from any scientific theory (Humphreys 2019, 3)—they only come with a mathematical or computational interpretation. Also, the assumption is that formal templates only have mathematical content. Humphreys takes a representative example to be the Barabási-Albert preferential attachment model. It provides a formal derivation of the result that networks with a scale-free topology (i.e., those whose distribution follows a power law) emerge by way of a two-step procedure: First, there is a continuously growing network whose number of nodes steadily increases (*growth*); second, new nodes tend to connect to those nodes that are already highly connected within the network (*preferential attachment*). This result is simulated and relies only on a few mathematical assumptions about, for example, how the initial connections of the nodes look (Barabási-Albert 1999). The construction process of formal templates, such as the power law distribution template, differs from theoretical ones in that the former does not require a correction set that specifies the need for adjustment of the computational template to match the empirical data in light of its empirical falsity (Humphreys 2019, 3, fn. 10). At the same time, Humphreys argues that the proper empirical justification of the transfer of formal representational devices – e.g., of the power law distribution template – is given by empirically checking whether the construction assumptions – e.g., of the preferential attachment template – are 'representationally correct' when applied to a particular system. It is only then that we are justified and thus can acquire knowledge about the causal process bringing about the phenomenon that the template represents. This is one reason why analogical reasoning alone is not a good guide to re-apply those formal templates to seemingly fitting systems. In the case of the power law distribution template, for example, the template might seem to be a representationally correct system. However, given that this and (more generally) other templates could in principle be derived from different kinds of construction assumptions, its application is properly justified only by making sure that the construction assumptions are representationally accurate in that application (see also Knuuttila and Loettgers 2012).

Because of their high degree of abstractness, formal templates lend themselves to interdisciplinary transfer. According to Humphreys, psychological aspects, analogical reasoning, and thus, anticipation and identification of vague resemblances between different target systems can only be heuristic devices in re-applying a template. Also, analogical reasoning stemming from the previous success of a template in some other domain could be used for justificatory purposes; both might even explain to some extent cases of template transfer. However, they cannot provide a proper justification for a template's transfer or re-application: "[T]he empirical justification for transferring a formal template ultimately rests on the satisfaction of the construction assumptions in the new domain" according to Humphreys (2019, 4). Because those assumptions are explicit, analogical reasoning is not necessary for template transfer. It is their abstractness, their independence from any physical interpretation, and the fact that assumptions are specified only according to the need given by the system in the target domain that is necessary for their transfer. On such a view, all empirical content of a formal template is only located in its empirical mapping, which implies that only knowledge of the target domain is required for its re-application (Humphreys 2019, 6). This is a view that appreciates the analogy-based approach as capturing the psychological and heuristic function of analogies in the context of discovery but rejects them as necessary to think about the object of transfer and thus understands model transfer within the context of justification.

Humphreys' template account offers important insights into model transfer in science. It is applicable to cases of model transfer within and across both the natural and the social sciences, especially those areas of the social sciences that use mathematical models. Besides the criterion of generality, Humphreys' tractability criterion explains, for example, why models from the natural sciences have been adopted by highly mathematized social scientific domains such as economics (e.g., Hindriks 2006; Lisciandra 2019). However, the concept of a template has limitations in understanding model transfer. While Humphreys has refined it towards a more fine-grained distinction between different kinds of templates (Humphreys 2019), the template concept is often still too general to be properly applied. For instance, when model transfer occurs from the physical to the social sciences, the template-based account neglects a number of elements. There might be potential preconditions for enabling the transfer, such as the commitment of scientists in the target domain to a specific modelling methodology, a set of concepts, or specific theories long accepted in that domain. Many analytical sociologists, for example, hold strong methodological commitments that profoundly shape their modeling choices, such as that human agents should be modeled as rational choice makers. Such factors conducive to transferring a specific kind of model are not acknowledged in the template-based account.

Indeed, epistemic and methodological features such as the structural similarity of phenomena in the source and target domain, a shared methodology in both domains, shared validation criteria for models depending on their purpose, or the goal of theoretical unification have been shown to play a role in enabling model transfer (e.g., Grüne-Yanoff 2011; Marchionni 2013; Tieleman 2022). Or, there might be specific methodological, epistemological, or conceptual features originating in the source domain that play a crucial role in preventing the transfer (e.g., Anzola 2019). For example, economists are strongly committed to epistemic values such as the predictive power of economic models rather than their ability to give causal explanations, or to conceptual commitments that their models should be conceptually compatible with the equilibrium concept. Economists have therefore been more open to model transfer if the transferred unit can accommodate their main commitments rather than the transfer leading either to a more fundamental conceptual and/or theoretical change of the neoclassical paradigm (Basso et al. 2017; Sent 2004; Thébault et al. 2018; Bradley and Thébault 2019) or to questioning their explanatory desiderata of using micro-founded models and providing general explanations (e.g., Marchionni 2013; Lisciandra 2019). In such cases, "when disciplinary conventions about … modelling play a larger role in dictating modifications of common templates, the tendency towards the kind of interdisciplinary organisation Humphreys identifies may not take place after all; disciplinary rather than interdisciplinary unity remains stronger" and thus, prevents model transfer (Marchionni 2013, 348). A further factor that could be relevant for explaining model transfer, especially from the physical to the social sciences and vice versa, is that social scientists might also implicitly hold on to non-epistemic values that play a role in their modelling choices. Such commitments might not only partially explain why a template is transferred, but also why some templates, although also general and tractable, might not be.

Humphreys' template-based account implicitly allows for building epistemological, conceptual, and methodological commitments via the construction assumptions. However, the specification process is not part of the explanation of the template's transfer. His account also leaves open questions regarding whether such factors are transferred together with the template and whether that would be relevant for explaining serious challenges and even failures of such transfers. More needs to be said about the nature and role of such commitments in enabling or preventing model transfer. In the next section, a few attempts by philosophers to take up those issues will be presented.

3. Open Issues in the Literature on Model Transfer

Most of the recent literature starts from a template-based account to think about model transfer. Taking a template as the unit of transfer seems to best capture essential features of model-based disciplines of contemporary science on the one hand, and an increasing cross-disciplinary engagement via the transfer of abstract mathematical tools and computational models on the other. However, the previously mentioned factors have been neglected. This section will present some of the efforts to extend the template-based account by focusing on three sets of issues.

One set of issues relates to the disagreement about the object of transfer and its features, which could explain why some models are transferred while others are not. This disagreement goes beyond the nature of models as analogies or templates and also relates to the level at which model transfer should be studied. Some philosophers analyze modelling frameworks (Lin 2022) as the object of transfer. Others focus on case studies of particular models, such as, e.g., the Fisher model or the Ising model, to study how such models can give rise to transferrable templates (Morrison 1997; Knuuttila and Loettgers 2014; 2016; 2020; Price 2020). Yet others, most prominently Humphreys, consider highly generic mathematical forms, namely what Humphreys calls formal templates, such as, e.g., coupled harmonic oscillators, network models, or even probability theory, to be the objects transferred

(Humphreys 2004; 2019). Such disagreement might partly originate in the fact that in scientific practice, all those objects could be transferred; depending not only on what the object of transfer is, but also what can explain it. Consequently, sometimes the relevant object of philosophical analysis is a specific model, e.g., an interpreted or otherwise contextualised formal structure, while at other times it is the formal template alone. To capture this potential diversity in the object that is actually being transferred, the existing conceptual proposals of formal, theoretical, computational, and model templates provide a useful starting point for thinking about the nature of the object of study, as well as the level of abstraction at which model transfer should be studied in different cases to understand how it can be explained.

Recent philosophical research on model transfer has further elaborated on Humphreys' account to address the relevant unit of analysis for model transfer. Houkes and Zwart (2019) point to a tension arriving from the functions of a template as a representational device on the one hand, and allowing for quantitative manipulation on the other. According to them, this tension arises because computational performance can compromise the representational function in the template's reduction to computation-enabling formal structures (2019, 93). By studying the case of the Lotka-Voltera model as applied to the diffusion of technological innovations, they do not define the notion of a template in terms of a purely formal structure from which its interpretation can be detached before its transfer, proposing instead to reconceptualize Humphreys' notion of a 'template.' They show that in some cases, such a formal structure comes with an inseparable and intended 'thin' intentional interpretation reflected in the construction assumptions that, for example, specify the variables of a differential equation or the generic mechanism the equations describe. This interpretation is different from Humphreys,' which they call 'analytic interpretation,' which is added when turning a template into a computational model. Acknowledging the difference between both kinds of interpretations allows for distinguishing between transferring a mere formalism (a formal template in Humphreys' proposal) and a template, in which case the formalism together with the intentional interpretation is transferred across domains. The distinction between analytic and intentional interpretation allows for templates to fulfill a dual function. It allows retaining the usefulness of the notion of a template to study cross-domain transfer while acknowledging that what is transferred can have proper representational functions despite being different from the application-specific computational model that is grounded in a template.

An account that aims to revise Humphreys' proposal more fundamentally in light of scientific practice has been proposed by Knuuttila and Loettgers (2014, 2016). They introduce the notion of what they call a 'model template' to not only account for what is transferred, but also to explain why it is transferred. By studying cases such as the Ising and spin glass models and their transfer from statistical mechanics into neuroscience and socio-economic systems, Knuuttila and Loettgers show that generality and tractability are not the only characteristics that explain their inter- and intradisciplinary transfer. Rather, it is also the general conceptual idea associated with the mathematical form together with a set of computational methods that makes them attractive for model transfer. On their definition, a model template consists of the mathematical structure – the template – that is complemented by a general conceptual vision associated with it, "that is capable of taking on various kinds of interpretations in view of empirically observed patterns in materially different systems" and that explains its transfer via its mediating capabilities between different target systems (Knuuttila and Loettgers 2016, 396). Such a conceptual idea is equally independent from a specific target system, but at the same time, allows for the application of computational methods and equations associated with a specific template. It is thus the conceptual framework coupled with a formal template that renders the model template applicable to a specific set of phenomena in different domains and thereby explains the model transfer. Importantly, this application can be achieved by relying on analogical reasoning.

The notion of a model template is in many respects a significant advancement in further clarifying Humphreys' different templates. Whether conceptual (as well as methodological) features play a role in enabling the transfer is particularly important to consider when those features might not align across domains that concern substantially different subject matters. The conceptual features of a model in physics to predict magnetic moments, for example, might *prima facie* not be shared and easily justifiable in the social sciences that model the behavior of human agents.[1] If they indeed played a role in enabling the transfer, the underlying ontology and conceptualization might constrain the kinds of domains the template can be transferred into in each case. To what extent the general conceptual idea constrains a template and its application also seems to depend on the level of abstraction at which model transfer is studied. If the formal template is the unit of transfer, for example, in cases of transferring specific distributions or purely mathematical equations, the conceptual vision attached to the template can help in identifying specific patterns that those equations could describe.

However, at a high level of abstraction, while a conceptual vision often seems to be a central ingredient of a template, it does not have to be part of all our philosophical template concepts. If we consider a theoretical template, such as Newton's second law, a conceptual vision of some person being described as behaving as the sum of individual forces that can be added up by vector addition indeed constrains the application of this template to only entities whose behavior can be described in this way (Humphreys 2019, 3). In this case, Humphreys' concept of a theoretical template might be satisfactory to capture the conceptual vision through the larger theoretical framework the template is a part of. That is not to say that the concept of a theoretical template is always sufficient. In other examples, it becomes clear that the concept of a theoretical template might fit specific cases but not others. One clear difference between the concepts of theoretical and model templates is that the latter is not bound to a specific theoretical context while the former is. Dynamical systems theory as well as network models are thus examples of templates that do not seem to be part of a specific theoretical framework but nevertheless come with conceptual content attached to them, for instance, different systems behaviors, kinds of interactions, or network structures the mathematics of those templates could capture. Consequently, given that both concepts are useful supports the view that a pluralism of templates is required if the diverse set of transferred objects should be captured by our philosophical concepts. Thus, even though Knuuttila and Loettgers argue for the unificatory power of the notion of a model template, a one-case-fits-all template concept might neither be desirable nor possible. Provided the varieties in which models occur (for an overview, see Frigg and Hartmann 2020) and the existing disagreement about the exact object of transfer, the question of what concept is best used to capture the object of transfer might have to be answered on a case-by-case basis.

A second set of issues relates to the question of what the characteristics of the transfer process are. For some time philosophical analyses implicitly assumed that model transfer occurs without substantially changing the model throughout the process; and indeed, this can be the case. Rational choice models in economics – subsumed under the label of 'economics imperialism' – have been transferred into fields such as sociology, political science, or anthropology and often without any conceptual or theoretical change. However, that the object transferred does not undergo any change seems unrealistic, as illustrated by a number of recent case studies. Rather, significant changes in the model are often crucial for its transfer (Herfeld and Lisciandra 2019; Knuuttila and Loettgers 2013; 2014). For example, models from engineering have been used in synthetic biology only after extensive modification and rational choice models also had to be adapted to the various target systems in the domains into which they were transferred (e.g., Knuuttila and García-Deister 2019; Grüne-Yanoff 2011; Herfeld and Doehne 2019). To capture such modifications, template-based approaches focus on the transfer process as a model construction process (or "template-to-target mapping" as Kaznatcheev and Lin 2022 have labeled it) by adding construction assumptions and an interpretation that allow for a derivation of an output representation (Humphreys 2004, 2019; Tieleman 2022). On this view, the template itself remains unchanged and its modification is dependent on the target system.

Price (2019; 2020) has studied in detail how the target domain shapes the modification of the model template being transferred and how the target domain might itself be changed to enable the model transfer. Employing Knuuttila and Loettgers' notion of a model template, Price notes that the general conceptual vision and thus some basic ontological commitments that come with the template have to be compatible with the target system in the domain the template is transferred into. Price thinks of this as a preparation process for which he introduces the notion of a 'landing zone,' basically referring to a model's envisaged target system providing an ontology that enables the template transfer. Price discusses the case of the topological atom as a landing zone for transferring a set of model templates from physics into chemistry to construct and apply the so-called quantum theory of atoms to molecules. Broadly defined as a mathematical model's target system, a landing zone enables the transfer and use of the model's mathematics – of a model template – in a new target domain by shaping the way in which the model becomes designed to ensure its applicability in the new domain (Price 2019, 22). Because the landing zone identifies the ontological features of a target system that enable the use of a template in that domain, it can also suggest possible modifications of the template in light of changes in ontological commitments needed to apply the template.

Other philosophers who acknowledge that templates are not static entities have proposed different notions to describe this modification process. Bradley and Thébault (2019), for example, introduce the distinction between 'model imperialism', an extension of the scope of problems addressed with the same, unmodified interpreted model, and 'model migration' which describes model modification in terms of a radical reinterpretation of the original model requiring what they call a 're-sanctioning' of the fundamental idealising assumptions to enable the model's application in the new target domain. Others have proposed the view of this process as one of translation (Herfeld and Doehne 2019) and have discussed the role of informal features as complementing features of the formal model, such as model narratives in this translation (Quack and Herfeld forthcoming). Given that such discussions are highly case-dependent, more systematic and conceptual work is needed to work out what such 'translation' exactly entails. Moreover, the relations between a model template, the source domain, and the target domain can be very complicated. Enabling the transfer of a model might entail rethinking basic principles and methodological commitments, or revising accepted theoretical frameworks in the target domain (Knuuttila and Loettgers 2014). Transferring a model from mathematical game theory into political science, for example, required not only the specification of construction assumptions and an interpretation, but a substantial reconsideration of the methodologies accepted to study political phenomena (Quack and Herfeld forthcoming).

The transfer might also lead to such substantial modifications of the model in that its original identity as an epistemic object is affected. Kaznatcheev and Lin (2022) show how model transfer can imply that the template switches from a theoretical modelling mode into an experimental measurement mode. This implies, in turn, that the process of template-to-target mapping can be quite complex. To appreciate this complexity, they introduce the distinction between conceptual and concrete mapping. The former maps the formal template and the theoretical concepts in the target domain, which they understand to be similar to the intentional interpretation introduced by Houkes and Zwart (2019). While after the conceptual mapping, the template still lacks empirical content, the concrete mapping from concepts to concrete objects in the target domain allows empirical content to enter the template, which Kaznatcheev and Lin (2022) understand to be similar to Houkes and Zwart's analytic interpretation. They also show that in their case of the transfer of game theory from mathematical oncology into experimental cancer biology, it is already in the first step that the conceptual mapping could be separated from the template, which suggests that not all templates come with a conceptual vision attached to it.

How a model's identity is affected by the transfer also raises questions about the role of the modeler in enabling model transfer and the kind of knowledge that is required on the side of the researcher to do so. While most template-based accounts keep the modeler out of the picture and limit the expert knowledge needed to that of the target domain (e.g., Humphreys 2019), some cases of model transfer require knowledge of the source domain, for example, about its theoretical and technical languages as well as its modeling practices, to engage with the template as a formal framework, interpret the template, repurpose the template, and anticipate its epistemic potentials (Bradley and Thébault 2019; Kaznatcheev and Lin 2022; Lin 2022). Lin (2022) has furthermore argued that sometimes so-called 'spillovers' – defined as knowledge-claims that are "indispensable to the justification of another knowledge-claim" (Lin 2022, 6) – are essential for the justification of a model's reapplication. An important question is why scientists engage in model transfer in the first place. Aside from the general importance of having tractable representations in science, the structural similarity of the target system, a shared methodology, or the goal of theoretical unification, different social and psychological factors might be involved: opportunism, attempts to imitate success, the lack of a comparable alternative, and finally 'imperialist' tendencies have certainly initiated model transfer processes in the past (e.g., Mäki et al. 2018).

Some philosophers have pointed out the importance of considering the relation between the researchers involved in the transfer and those in the source and target domains to understand the degree of model modification in the transfer. Grüne-Yanoff (2011) discusses the degree of modification in the case of transferring game theoretic models from economics to biology and back. He argues that a modeler's knowledge of, the degree of modification of, and reference to, the original model is inversely proportional to the influence of the modeler in the transfer process and their distance to the source domain. Such relations can tell us a lot about the degree of model modification in transfer processes. In the case of imperialistic transfers, for example, a model from some source domain is applied to a set of problems traditionally tackled in some target domain that is distant from the modeler that applies the model to those problems. Economists applied rational choice models to problems – be that crime, addiction, discrimination, marriage decisions, or breastfeeding – traditionally studied in fields that were distant to them and did so without substantially changing the models (e.g., Becker 1976). In contrast, when biologists transferred game theoretic models into their own discipline, core concepts and formal results of game theoretical models – such as players, strategies, and payoff matrices – were re-interpreted and successively replaced by biologists' own theoretical constructions (e.g., Grüne-Yanoff 2011, 389). For instance, while core concepts and formal results of game theoretical models – such as players, strategies, and payoff matrices – were initially imported into, and re-interpreted in biology, biologists would successively replace them with their own theoretical constructions (e.g., Grüne-Yanoff 2011, 389). Considering this distance between modeler and the respective domains to which a model is transferred can thus be informative in that it tells about the nature of the transfer and the degree of modification it brings with it.

A final set of issues that has not yet been extensively addressed in the literature on model transfer concerns the relationship between model transfer and scientific progress. In parts, this gap in the literature originates in the lack of an explicit discussion of the challenges that hamper model transfers or prevent them from being successful. The existence of such challenges most likely depends upon the factors that need to be in place to enable a model's transfer in the first place (e.g., Price 2019). Aforementioned factors that might hamper model transfer, such as structural dissimilarities between templates and target systems or differences in accepted methodologies in both domains, might certainly play a role (Grüne-Yanoff 2011; Knuuttila and Loettgers 2016). However, given that the philosophical literature has focused mostly on cases of successful model transfer, there is not yet a systematic discussion about how model transfer might generally lead to empirical, theoretical, or conceptual progress—or prevent it. A philosophical analysis of the relation between model transfer and progress would be important. Progress may only be an apparent result of model transfer. Particularly when models are substantially modified in the transfer process or when they imply profound theoretical and methodological changes in the target domain, their epistemic contribution to a better empirical understanding of phenomena in the target domain, and more generally, might not be straightforward.

For template-based accounts, model transfer and scientific progress seem to be closely connected, in that progress is frequently achieved by applying tractable mathematics. For instance, Humphreys observes that "whenever you have a sudden increase in usable mathematics, there will be a sudden, concomitant increase in scientific progress in the area affected" (Humphreys, 2004, 55). To discuss conceptual progress, Price (2020) focuses on the relation between the unit of transfer and the target system to which it is applied (i.e., the landing zone). On his view, the reconceptualization of the phenomenon in the target domain required for model transfer can lead to conceptual progress. Template transfer can provoke discussions about the appropriate ontology for applying the model and about the appropriate assumptions and motivate theorizing in the new domain. Insofar as the resulting conceptual pressure leads to changes in, or replacements of, concepts of the target domain, it can lead to the emergence of new concepts and thus to conceptual progress in that domain. Similarly, such conceptual pressure can be perceived as a threat to an existing conceptual framework that needs to be avoided. The existence of such pressures can thus challenge or even prevent model transfers.

Boumans and Herfeld (2023) offer another proposal to appreciate the different ways in which model transfer can lead to epistemic benefits in the target domain. By studying a historical case from econometrics, they explore the way in which a functional account to progress can be used to analyse ways in which model transfer can lead to progress. This so-called new functional approach defines progress in terms of usefulness for defining and solving problems (Shan 2019). Applied to model transfer, epistemic benefit is then translated into the usefulness of a model not only for solving concrete problems in some domain but also for proposing, refining, and specifying new problems and thereby guiding future research in some domain. Templates are part of a "common recipe" consisting of a set of concepts; a set of practical guides specifying the procedures and methodologies as a means to solve a problem; a set of hypotheses, and a set of patterns of reasoning indicating how to use other components to solve a problem (Shan 2019, 745). As such, this account already provides indicators to think concretely about success conditions for model transfer as well as reference points to identify some of the major challenges to model transfer in science. By adopting this account and the concept of a model template, Boumans and Herfeld show that the conceptual vision of the business cycle in a core econometric model template was essential to its construction and transfer, but that the resulting progress was also disrupted when the conceptual vision of the phenomenon changed in such a way that the template transferred is no longer considered to be sufficiently representative of the phenomenon in question.

4. Conclusion

Given that the philosophical analysis of model transfer as a prominent phenomenon in modern science is only in its beginning stages, this survey has pointed out open issues that should be addressed to advance the debate further. Surveying the literature not only reveals the relevance of the phenomenon but also shows its philosophical importance for multiple areas within philosophy of science. Reaching a deeper understanding of model transfer and its challenges in science will have profound implications for the way in which we think about scientific models, the practice of modelling, and model integration in philosophy of scientific modelling.

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[1] For a case from econophysics suggesting that the conceptual vision underlying physical models of the behavior atoms might hinder applying them to freely choosing agents, see Bradley and Thébault (2019).