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Representing Non-actual Targets?

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Abstract

Models typically have actual, existing targets. However, some models are viewed as having *non*-actual targets. I argue that this interpretation comes at various costs and propose an alternative that fares better along two dimensions: (1) agreement with practice and (2) ontological and epistemological parsimony. My proposal is that many of these models actually have actual targets.

1. Introduction

Scientists reason about targets of interest by representing them with models. The models allow conclusions to be drawn about their targets, namely, the things of which they are surrogates. Typically, models have real-world targets or, more precisely, *actual* targets. Actual targets are those that exist in the actual world. However, some models don't appear to have actual targets in that sense. Models with ostensible non-actual targets present various issues for accounts of scientific representation and for our understanding of scientific practice.[1] Section 2 shows that talking of non-actual targets either makes representation at odds with practice or requires making potentially unnecessary ontological or epistemological commitments. In section 3, I argue that we should instead interpret many models as having actual targets. I illustrate with cases from physics, biology, and economics. Section 4 discusses potential objections and section 5 concludes.

2. Targets, representation, and models

Models represent their targets. We usually understand targets to be "parts of the world" (Elliott-Graves 2020), a "selected part or aspect of the world" (Frigg and Nguyen 2020), or "sets of real-world properties" (Weisberg 2013). Some models support surrogative reasoning, namely, they allow one to reason and make inferences from the model to their targets (Swoyer 1991). We learn about the properties and

[1] It should be noted that this is *not* the problem of the ontological status of models. See section 4.1 for a short discussion.

features of targets by studying surrogates, the models. Importantly, models and targets are distinct objects or systems; we use the former to make inferences about the latter. Models that support surrogative reasoning are *epistemic* representations (Contessa 2007). Typically, models have *actual* targets. Actual targets are those that "exist" in the world, for instance, zebras, the Canadian economy, or the SARS-CoV-2 virus. However, some models don't appear to have actual targets in that sense. To give a few examples, the ratchet and pawl machine; Maxwell's vortex model of the ether; models of XNA; models of n-sex populations, where n is sufficiently large; the Hawk–Dove model; or general equilibrium models prima facie don't seem to be about anything that exists in the world. After all, there is no (and cannot be any!) perpetual motion machine, ether doesn't exist, and to the economists' great dismay, economies aren't in general equilibrium. This has led many commentators to say that the targets of such models are "fictional," "imaginary," "nonexistent" or that the models are "targetless" or "hypothetical" (e.g., Frigg and Nguyen 2020; Knuuttila and Koskinen 2020; Levy 2015; Massimi 2019; Suárez 2015; Weisberg 2013). To simplify, let's call them *models with non-actual targets*. Models with actual targets can be used to make inferences about actual parts of the world, and models with non-actual targets can be used to make inferences about non-actual parts of the world. Targetless models cannot be or aren't used to reason about actual or non-actual parts of the world.[2]

Models with non-actual targets raise two interrelated issues. The first is that if models don't have actual targets, then it is not clear whether they are, or can be, successful epistemic representations. Some accounts of representation require that epistemic representations denote their targets (e.g., Contessa 2007; Elgin 2017; Frigg and Nguyen 2020). Denotation is a relation that obtains between a designatum and a denotatum, that is, the thing designated. Without a denotatum, there is no denotation relation. Denotation failure implies that the representation is either not successful or not epistemic. For instance, suppose a model user intends the model to denote a target. But if, in fact, the target doesn't exist, then the model doesn't support surrogative reasoning for that target. More generally, if the target is non-actual, then it seems there is nothing we can reason about.

However, as we will see in more detail in the next section, this is a conclusion at odds with scientific practice. If models with non-actual targets don't qualify as epistemic representations, then they shouldn't support surrogative reasoning. The problem is that a naturalistic interpretation of these models and their use compels us to conclude that scientists make informative inferences on their basis. Pace our accounts of representation, if that is the case, then models with non-actual targets are genuine, successful, epistemic representations. Therefore these models must license inferences about *something*.

The second issue is that if we grant, following practice, that many models with non-actual targets are successful epistemic representations, we still have to provide an account of those non-actual targets' "existence." One potential avenue consists in saying that the targets *are* possibilities.

[2] *Targetless* is sometimes used in the literature to refer to models with non-actual targets or to models that are studied for their own sake, for example, cellular automata (Weisberg 2013, sec. 7.3). Here I am concerned with models that *do* have a target, but that target is ostensibly non-actual.

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> The first question about hypothetical modeling can be settled simply: What are the targets of these models? *Ex hypothesi*, their targets are nothing at all. With a little more nuance, we can say that the targets of hypothetical models are possibilities. Explaining how hypothetical models can tell us about such possibilities would require a lengthy discussion about the metaphysics of possibilities, which is beyond the scope of this book. (Weisberg 2013, 121, emphasis original)

Weisberg appears to follow a tradition that attributes existence to non-actual objects or entities (e.g., Lewis 1986). This explains the epistemic status of models with non-actual targets; models allow one to reason about non-actual targets because there *are* such targets. Another avenue, defended, for instance, by Suárez (2015, 44), is to view these models as being "representations with fictional or imaginary targets". Whether the target exists is irrelevant for a model's capacity to serve as an epistemic representation. According to Suárez, what matters are the inferential norms modelers use to make legitimate moves from model to target.

Both avenues have the benefit of accounting for how models with non-actual targets can be used for surrogative reasoning. In Weisberg's case, we make inferences about possible targets and in Suárez's, about fictional ones. However, that sort of solution comes at a nontrivial cost, namely, an apparent ontological commitment to either possible or fictional objects and to an applicable epistemology. Indeed, the ontological and epistemological status of possible and fictional objects is fraught with difficulties. What these objects could be, whether there are such objects, and how we can know their properties are all controversial issues. Possible and fictional objects seem especially problematic in a scientific context since scientific claims usually obtain their justification by facing the tribunal of experience. It is not straightforward, to say the least, how we are supposed to have empirical access to these objects or assess the similarity between a model and its target if the target is non-actual (Suárez 2009, sec. 5). Because we presumably want that what makes scientific claims true are facts about the world, we still need a story about what connects those facts to non-actual targets. Another way to formulate the worry is in terms of truthmakers: what are the potential truthmakers of claims about possible or fictional objects?[3]

All that being said, I should note that there are various, coherent ways one can deal with non-actual targets. There is nothing intrinsically mistaken with positing the existence of possible targets or denying that models with non-actual targets provide successful epistemic representations. However, as the previous discussion suggested, I believe accounts of models with non-actual targets should satisfy the following two desiderata:

1. agreement with practice,
2. ontological and epistemological parsimony.

First, accounts of models with non-actual targets should make sense of their use for surrogative reasoning. If scientists successfully use those models to reason about

[3] One could endorse a deflationary theory of truth like those that Suárez (2015) discusses. However, this is also contentious, and it is an open question whether we can make sense of truth without (substantive) truthmaking (e.g., Asay and Baron 2020).

targets, as it seems they do, then our interpretations of the practice shouldn't view them as misrepresenting or failing to be genuine epistemic representations. Second, we should refrain from positing unnecessary or problematic entities. Other things being equal, a simpler ontology and epistemology is preferable to one that involves contentious objects. Some accounts do very well regarding (2), but usually at the cost of (1). Other accounts score well on (1), but at the price of arguably more contentious commitments about (2). For instance, of the accounts we have discussed, Elgin (2017) and Frigg and Nguyen (2020) are parsimonious but run counter to practice insofar as scientists successfully use these models for surrogative reasoning. Conversely, Weisberg (2013) and Suárez (2015) account for practice but posit problematic entities. I contend that there is another interpretation that does better on both dimensions.

3. Actually, the targets are actual

In short, I want to argue that we can interpret most models with ostensible non-actual targets as having, in fact, *actual* targets.[4] Recall that actual targets are actual parts of the world and that non-actual targets are non-actual parts of the world. Thus what I want to show is that models with ostensible non-actual targets are used to reason about actual parts of the world, not non-actual ones. This would prima facie satisfy our two desiderata in one go. If the target is actual, then we can easily account (1) for successful epistemic representation and (2) for its ontology and epistemology. It is uncontroversial that models can denote actual objects and that we can know about them with the usual empiricist epistemology. What I take these models to do is to support surrogative reasoning about properties of actual parts of the world. In the following pages, I briefly examine three cases of models with ostensible non-actual targets across the sciences: the ratchet and pawl machine in physics, the Hawk–Dove model in biology, and general equilibrium in economics. The cases are short, but their variety and the textual evidence should provide compelling grounds to reject the non-actual target reading.

3.1 Ratchet and pawl machine

One interesting example that Weisberg (2013) discusses is the ratchet and pawl machine (Feynman et al. [1963] 2010, chap. 46), a perpetual motion machine model. The model exemplifies various properties, for instance, Brownian motion, being a heat engine, the laws of thermodynamics, and perpetual motion—or lack thereof. Within the model, perpetual motion would only be possible if the laws of thermodynamics were not to hold. Of course, there isn't and cannot be any perpetual motion machine. Weisberg concludes that the model has a nomologically impossible target. The target would thus be impossible parts of the world.

At first sight, this seems like a prime candidate for a model with a non-actual target. However, this is puzzling because Weisberg also states that we can use the

[4] Whether *all* such models have actual targets is an open question. My claim is more modest, namely, that it is a better interpretation of various cases discussed in the literature. For instance, I also believe this would be the correct interpretation for models of XNA (Weisberg 2013, sec. 7.2.1) or supersymmetric particles (Massimi 2019).

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model for making inferences about the actual world. For instance, he says that "from models of nomologically impossible systems, we can learn why our world cannot have the model system and what laws of nature would have to change in order to make this merely a contingent fact" (128–29). "Our world" is certainly not a non-actual target. If we use the machine to understand why our world doesn't and cannot contain perpetual machines, then we are reasoning about actual parts of the world, namely, an actual target.

Weisberg's claim that the model can be used to reason about the actual world is the correct one and agrees with practice. In his *Lectures*, Feynman recounts that the discussion of the ratchet and pawl machine came to help "to devise an elementary explanation, from the molecular or kinetic point of view, for the fact that there is a maximum amount of work which can be extracted from a heat engine" (Feynman et al. [1963] 2010, 46-01). The discussion suggests to "try to invent a device which will violate the Second Law of Thermodynamics" (46-01). This doesn't work (unsurprisingly), and he concludes that we "evidently have a fundamental proposition that there is no way to design a machine which, left to itself, will be more likely to be turning one way than the other after a long enough time" (46-07). That sort of conclusion has several real-world practical effects. For one, the United Kingdom's *Manual of Patent Practice* states that "processes or articles alleged to operate in a manner which is clearly contrary to well-established physical laws, such as perpetual motion machines, are regarded as not having industrial application" (Intellectual Property Office 2016, para. 4.05). Would-be inventors routinely propose designs of machines that would violate the laws of physics, and some cases even go to court (Wadlow 2007). Patent examiners reject designs of alleged perpetual motion machines because they can infer that the machine wouldn't work in the actual world. When we use perpetual machine models to understand why we cannot successfully build such machines or why a particular machine won't produce an infinite amount of work, we are reasoning about actual parts of the world, parts that we conclude cannot contain perpetual motion machines.

3.2 Hawk–Dove model

Another case of a model with an ostensible non-actual target is the Hawk–Dove model of animal competition as used in biology (Maynard Smith and Price 1973; see also Maynard Smith and Parker 1976). It is a game-theoretic model of behaviour in situations of conflict over resources. Instead of engaging in costly conflicts, members of the same species often display restraint and settle conflicts conventionally. A standard explanation for that phenomenon, Maynard Smith and Price (1973) note, was that of group selection; restraint is selected because of its fitness benefits for the species. One goal of the model was to show that it was possible to explain the phenomenon using only individual selection.

As in the previous case, there is also an equivocal interpretation of the model. For instance, Rice (2016; see also Rohwer and Rice 2013; Sugden 2011) offers competing readings of the model. On one hand, he says that it is a model of a hypothetical scenario that is "not intended to accurately represent any particular features of a real-world system—i.e. the model has no real-world 'target system' whose (difference-making) features it aims to accurately represent" (Rice 2016, 91). On the other

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hand, he also argues that "modeling these possible systems via a hypothetical scenario is often sufficient to produce factive scientific understanding of a phenomenon" (91). In a nutshell, understanding amounts to grasping true information about phenomena. Both interpretations appear inconsistent, for if the model has no real-world target, then we shouldn't be able to use it to make true inferences about actual phenomena. And if we can use it to draw such inferences, then the model must have a real-world, actual target. To reason about actual phenomena with a model implies that the model has an actual target.

Again, this second interpretation is harmonious with practice. Maynard Smith and Price's (1973) motivation for the Hawk–Dove model is to provide a possible explanation of an actual phenomenon, namely, restraint in combat. Later in the article, they conclude that their results are "sufficient to show that individual selection can explain why potentially dangerous offensive weapons are rarely used in intraspecific contests" (Maynard Smith and Price 1973). More generally, Maynard Smith (1978, 52) say that the role of optimality modeling, as exemplified by the Hawk–Dove model, "is not to demonstrate that organisms optimize. Rather, they are an attempt to understand the diversity of life." Of course, the "diversity of life" is an abstract target (more on that in section 4.2). Yet, it surely is actual; life is actually diverse, and we want to understand why it is so. Although Maynard Smith and collaborators use highly idealized models, they nevertheless use them to reason about actual biological phenomena.

3.3 General equilibrium

A seminal moment in the development of economic theory was the proof of the existence of general equilibrium by Arrow and Debreu (1954). They proved that, for all economic systems that satisfy a certain set of assumptions, there is a competitive equilibrium. These assumptions are so unrealistic that no actual economic system (jointly) instantiates them. There are various interpretations of general equilibrium modeling, some viewing it as a targetless model, others simply as a failed representation of actual targets (e.g., Blaug 2003). But another interpretation related to the model's role as a benchmark suggests that the model has a non-actual target, for if the model allows us to learn about the properties of an ideal, competitive, economic system, then this target doesn't seem actual.

However, that benchmark role serves two important purposes related to actual parts of the world. First, as Arrow and Debreu (1954, 265) note, "descriptively, the view that the competitive model is a reasonably accurate description of reality, at least for certain purposes, presupposes that the equations describing the model are consistent with each other." If the competitive model has no solution, then this suggests that the world doesn't (or perhaps cannot) operate according to the model (see Verreault-Julien 2017). On the contrary, if there is a solution, then this licenses the inference that the actual world might work as per the model.

Second, the benchmark serves to "measure the dysfunction of the real world" (Athreya 2013, 33). Economists compare Arrow–Debreu systems to actual economies or markets to learn about their (actual) inefficiencies. For instance, we may infer that a given market is inefficient because of the presence of informational asymmetry.

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We thus can understand why there is an *absence* of equilibrium. Or, we can make inferences about the sort of policies that might contribute to removing these inefficiencies.[5] In both cases, the model's target is the actual world.

The three foregoing cases illustrate that we can often easily interpret models with ostensible non-actual targets as actually having actual targets.

4. Back to the desiderata

In section 2, I submitted two desiderata that accounts of models should measure up to, namely, (1) agreement with practice and (2) ontological and epistemological parsimony. Considering the cases just presented, one might reject that viewing the targets as actual really constitutes an improvement regarding the desiderata. I discuss potential objections.

4.1 Agreement with practice

First, one might object that some models do have a non-actual target. My claim is not that *all* models have actual targets; rather, it is that typical cases discussed in the literature are best interpreted as having actual targets. Maybe some models have non-actual targets. For instance, let's consider Maxwell's vertex model of the ether, often referred to as an example of a model with a non-actual target (e.g., Massimi 2019; Suárez 2015). Of course, ether doesn't exist, and so it cannot be an actual target. The model is a prime illustration of how important it is to properly distinguish between a model's representational content and its target.[6] This point is crucial; the representational content need not be identical to the object we reason about.[7] Consider literary fiction, where this mismatch often occurs. One target of George Orwell's *Animal Farm* isn't a farm ruled by talking pigs but communism under Soviet rule (Frigg and Nguyen 2020, 208–9). Likewise, models often contain idealizations or fictional entities that help us reason about actual objects. But these idealizations and fictions are rarely, if ever, the objects we make inferences about, namely, the targets. Instead, they are an expedient way of making features salient or of exemplifying them. If a model would take ether as its target, then it wouldn't have an actual target. In fact, we may want to say that it fails to have a target and is thus target-*less*.[8] However, if the model is also used to make inferences about electromagnetic phenomena, then the target surely is actual. This also means that a model may misrepresent some aspects of a target by suggesting incorrect inferences (e.g., ether has properties *P*), while simultaneously representing others correctly (e.g., electromagnetism has properties *Q*). And sometimes models have a "moving target" (Weisberg 2013, sec. 7.4); scientists may use a model to make inferences about parts of the world, realize they don't exist, and then change the target.

[5] My point doesn't hinge on whether the Arrow–Debreu model *correctly* licenses inferences about actual targets, only that it has such targets.

[6] By *representational content*, I mean what Frigg and Nguyen (2020) call *manifest content*, namely, the content of the representation itself and not what is specifically imputed to the target.

[7] Which is also why our theories of representation need to allow for model–target discrepancies. Suárez (2004) and Frigg and Nguyen (2020, chap. 8) are examples of such theories.

[8] Massimi (2019) also uses the label "targetless" to describe the ether model, but not in the same sense of failure that I use here.

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One might still object that taking practice at face value demands viewing the models as representing non-actual targets. For instance, the ratchet and pawl model would *really* have a perpetual motion machine as its target and not, for example, actual heat engines. One powerful argument in favor of that claim comes from the semantic view of theories, which conceives them as collections of models. Of these models, many will represent *possible* states of a system. Assuming that the semantic view is correct, this prima facie suggests that models do have non-actual targets.

My reply is twofold. First, I suspect that this objection stems from a conflation between the ontology of model systems and the ontology of their targets. For instance, many have suggested that models are akin to fictions (e.g., Godfrey-Smith 2006). The key point here is that a model system might very well be a fiction, yet its target may be actual. My claim that many models have, in fact, actual targets is agnostic with respect to the ontology of models. So we can grant that the face-value practice might involve building, for example, fictional representations and, at the same time, deny that targets are also fictional. In Elgin's (2017) and others' parlance, we could say that the ratchet and pawl model is a perpetual-motion-machine-representation but not a representation *of* a perpetual motion machine. Second, that models represent possible states of a system doesn't imply that said system is non-actual. To give a toy example, my theory of my coffee mug includes models that represent it as broken while, in fact, it isn't. But that theory's target is still my actual mug. That my mug is breakable is an actual property of my actual mug. Again, we need to distinguish between possibilities-representations and representations *of* possibilities.

4.2 Ontological and epistemological parsimony

Prima facie, actual targets don't seem to pose any ontological or epistemological challenges. However, one might worry that I have just moved the problem elsewhere. Indeed, what I propose implies to interpret, at least for some cases, the models as having a *generalized* target (Weisberg 2013, sec. 7.1). These targets abstract from the shared features of particular targets. Importantly, they are abstract but actual. For example, one might be interested in restraint in combat *in general* instead of specific instances of it. Generalized targets don't seem so parsimonious.

I think the worry is exaggerated: *all* target systems abstract, to some extent, from the phenomena (Weisberg 2013, sec. 5.3.1) (and phenomena themselves arguably abstract over data; Woodward 2011). Even the target of a specific and local phenomenon is only a subset of the total phenomenon's properties. A generalized target is simply more abstract, and its abstractness is a matter of degree, not of kind. From information about heat engines in general, we can infer, as do patent examiners, that a specific design won't produce an infinite amount of work.

However, this doesn't directly answer the parsimony concern. Therefore my claim is comparative: a commitment to abstract actual parts of the world is more parsimonious than a commitment to non-actual ones. For if non-actual objects have any sort of existence, it will be as an abstract object or a related notion. But denying their actuality opens the door to various philosophical issues, especially those related to truthmaking. In short, it is easier to account for the truth of the inferences we make about targets if said targets *exist* in our actual world rather than in some other

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possible or fictional world. If truth indeed depends on being, then that there "is" something certainly facilitates our judgments about truth.

Finally, models qua epistemic representations support surrogative reasoning: they help us draw conclusions about "something else." Even if one would prefer to view that something else as being theories or other models instead of parts of the world, positing non-actual objects is unnecessary. Whatever existence theories and models have, it isn't in a non-actual world but in ours. What this suggests, however, is that our current accounts of targets may not be sufficiently open to the diverse nature of targets (see Elliott-Graves 2020).

5. Conclusion

Viewing models as having non-actual targets comes at nontrivial costs, namely, disagreement with practice and a lack of ontological and epistemological parsimony. To avoid paying those costs, I argued that in various cases, we can interpret the models as having actual targets. We can draw two key lessons from models with ostensible non-actual targets. First, we should be careful not to conflate a model's representational content and its target. The target is the object we use a model to reason about; it is not the model system itself. The second, more programmatic, is that we need better accounts of the types of objects or entities that may constitute targets. I approached the problem of models with ostensible non-actual targets through the lens of surrogative reasoning: models help us draw conclusions about "something else." That "something else" is typically assumed to be "parts of the world." Although we should, I believe, refrain as much as possible from positing non-actual targets, we should also be able to offer an alternative that explains how and why ostensible non-actual targets are, actually, actual parts of the world.

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References

Arrow, Kenneth J., and Gerard Debreu. 1954. "Existence of an Equilibrium for a Competitive Economy." *Econometrica* 22 (3):265–90.

Asay, Jamin, and Sam Baron. 2020. "Deflating Deflationary Truthmaking." *Philosophical Quarterly* 70 (278):1–21.

Athreya, Kartik B. 2013. *Big Ideas in Macroeconomics: A Nontechnical View*. Cambridge, MA: MIT Press.

Blaug, Mark. 2003. "The Formalist Revolution of the 1950s." *Journal of the History of Economic Thought* 25 (2):145–56.

Contessa, Gabriele. 2007. "Scientific Representation, Interpretation, and Surrogative Reasoning." *Philosophy of Science* 75 (1):48–68.

Elgin, Catherine Z. 2017. *True Enough*. Cambridge, MA: MIT Press.

Elliott-Graves, Alkistis. 2020. "What Is a Target System?" *Biology and Philosophy* 35 (2):Article 28.

Feynman, Richard, Robert B. Leighton, and Matthew Sands. (1963) 2010. *The Feynman Lectures on Physics*, vol. 1, *Mainly Mechanics, Radiation, and Heat*. New Millennium ed. New York: Basic Books.

Frigg, Roman, and James Nguyen. 2020. *Modelling Nature: An Opinionated Introduction to Scientific Representation*. Cham, Switzerland: Springer Nature.

Godfrey-Smith, Peter. 2006. "The Strategy of Model-Based Science." *Biology and Philosophy* 21 (5):725–40.

Intellectual Property Office. 2016. *Manual of Patent Practice*. https://www.gov.uk/guidance/manual-of-patent-practice-mopp/section-4-industrial-application.

Knuuttila, Tarja, and Rami Koskinen. 2020. "Synthetic Fictions: Turning Imagined Biological Systems into Concrete Ones." *Synthese* 198:8233–50.

Levy, Arnon. 2015. "Modeling without Models." *Philosophical Studies* 172 (3):781–98.

Lewis, David K. 1986. *On the Plurality of Worlds*. Oxford: Blackwell.

Massimi, Michela. 2019. "Two Kinds of Exploratory Models." *Philosophy of Science* 86 (5):869–81.

Maynard Smith, John. 1978. "Optimization Theory in Evolution." *Annual Review of Ecology and Systematics* 9: 31–56.

Maynard Smith, John, and Geoffrey A. Parker. 1976. "The Logic of Asymmetric Contests." *Animal Behaviour* 24 (1):159–75.

Maynard Smith, John, and George R. Price. 1973. "The Logic of Animal Conflict." *Nature* 246 (5427):15–18.

Rice, Collin. 2016. "Factive Scientific Understanding without Accurate Representation." *Biology and Philosophy* 31 (1):81–102.

Rohwer, Yasha, and Collin Rice. 2013. "Hypothetical Pattern Idealization and Explanatory Models." *Philosophy of Science* 80 (3):334–55.

Suárez, Mauricio. 2004. "An Inferential Conception of Scientific Representation." *Philosophy of Science* 71 (5):767–79.

Suárez, Mauricio. 2009. "Scientific Fictions as Rules of Inference." In *Fictions in Science: Philosophical Essays on Modeling and Idealization*, edited by Mauricio Suárez, 158–78. New York: Routledge.

Suárez, Mauricio. 2015. "Deflationary Representation, Inference, and Practice." *Studies in History and Philosophy of Science, Part A* 49:36–47.

Sugden, Robert. 2011. "Explanations in Search of Observations." *Biology and Philosophy* 26 (5):717–36.

Swoyer, Chris. 1991. "Structural Representation and Surrogative Reasoning." *Synthese* 87 (3):449–508.

Verreault-Julien, Philippe. 2017. "Non-causal Understanding with Economic Models: The Case of General Equilibrium." *Journal of Economic Methodology* 24 (3):297–317.

Wadlow, Christopher. 2007. "Patents for Perpetual Motion Machines." *Journal of Intellectual Property Law and Practice* 2 (3):136–44.

Weisberg, Michael. 2013. *Simulation and Similarity: Using Models to Understand the World*. Oxford: Oxford University Press.

Woodward, James F. 2011. "Data and Phenomena: A Restatement and Defense." *Synthese* 182 (1):165–79.

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