**Effects and Artifacts: Robustness Analysis and the Production Process**

**Abstract:** Scientists often use multiple independent methods of identification to distinguish reliable results from those produced in error (artifacts). This process is referred to as ‘robustness analysis’. I argue that even though robustness analysis is useful for differentiating natural phenomena from artifacts, it fails to differentiate experimentally produced effects from artifacts. I argue that to bypass this problem, we can re-frame the role of robustness analysis to focus on cross-comparison between methods of production. Focusing on the production relation provides information about *how* changes in conditions alter given effects, without first having to make a distinction between effect and artifact.

**1. Introduction.**

Scientists often use multiple methods of identification to distinguish reliable results from those produced in error. When methods converge on an object or process, inferences are made about reliability. For example, Perrin (1913) successfully used multiple independent methods of measurement and inference to converge on Avagadro’s number, thus supporting its objectivity. Unsuccessful convergence (or divergence) indicates error. Recently, disagreement has surfaced about the failure of reproducing results about an arsenic-consuming living organism (Reaves et al. 2012). In 2010 a novel discovery seemed to redefine how biologists understand the chemistry of living organisms by questioning whether phosphorous is necessary for cellular function. A bacterium in the arsenic-rich waters of Mono Lake was found. Under a set of specific experimental conditions the organism was found to replace phosphorous with arsenic in its DNA (Wolfe-Simon et al 2011). However, using more stringent, *independent* experimental conditions to eliminate phosphorous and to “purify” the DNA samples of any clinging arsenate, Reaves et al. (2012) did not find covalently bound arsenate in the DNA structure. The divergence in results indicates that there was an experimental error produced and that the original arsenic-consumption effect was an artifact of the lack of purification in the preparatory procedure.

This method of identification based on converging results is commonly referred to as ‘robustness analysis’. It is a methodological process of generating conclusions or results that converge over a variety of independent identifications, models, measurements, or derivations (Wimsatt 2007, 43). Philosophers of science have discussed robustness analysis in modeling[[1]](#footnote-1)as well as in experimentation and evidence.[[2]](#footnote-2) I focus on the latter. According to Wimsatt, robustness analysis grounds realism, reliability, and objectivity and distinguishes the ontologically and epistemologically “trustworthy” from what is unreliable (2007, 56). Specifically, it differentiates real objects, events, and processes from “artifacts”, which are results produced in error (2007, 38).[[3]](#footnote-3) The characteristic of “artifactual” results is that they are unstable in the context of multiple independent methods of identification (Wimsatt 2007, 56). To understand how stability/convergence and instability/divergence works, a bit of detail about the process of robustness analysis is necessary.

In robustness analysis, several independent methods converge on a common consequence despite independent conditions, abstractions, and idealizing assumptions (Levins 1966; Wimsatt 2007). This consequence, often referred to as a ‘robust consequence’, can be a prediction, property, or result.[[4]](#footnote-4) After the robust consequence is generated, a ‘robust theorem’ is created, which states the robust consequence *relatively* independent of the different conditions, abstractions, and idealizing assumptions.[[5]](#footnote-5) Wimsatt (2007) frames robustness analysis as an effective “heuristic” that can be used to show how a robust consequence does not depend on the different details of each method (56). These details are unstable between methods and thus their divergence fades into the background, while the robust consequence is set into focus. Wimsatt (2007) uses the example of detecting properties of planets with multiple independent imaging techniques. According to Wimsatt, if a given signal is weak and the noise of each imaging technique is strong, by combining techniques, the signal strength will increase while the different types of noise will not (2007, 57). The noise is independent, random, and differs between methods, while the signal is invariant and over each method.

At first glance, philosophical examples of robustness analysis, signal detection (Wimsatt 2007; Campbell 1966), ecological populations and species polymorphism (Levins 1966), predicting predator-prey relations using Lotka–Volterra equations (Weisberg 2006), climate change (Lloyd and Parker 2009; Lloyd 2010) do not seem to have anything particular in common about the *type of regularities* studied. They show diverse application of robustness analysis to physical and biological regularities. But these are all examples of using robustness analysis to distinguish *natural phenomena* from results produced in error. That is, in these types of examples objects, events, and processes are *discovered* by carefully comparing multiple independent methods of identification. To use a signal detection analogy, methods are fine-tuned so that the signal of a given regularity is made clear. However, there is a different type of regularity that requires careful differentiation and attention: effects that are experimentally *produced* rather than discovered.

Hacking distinguishes ‘phenomena’ and ‘effects’. He characterizes ‘phenomena’ as “observable regularities” (1983, 221). These are regularities that are not the result of experimental intervention—e.g., the planets and stars. According to Hacking, there are few phenomena in nature waiting to be observed but science is full of regularities that are produced through intervention as ‘effects’ (1983, 227).[[6]](#footnote-6) He distinguishes the two types of regularities:

Phenomena and effects are in the same line of business: noteworthy discernible regularities. The words ‘phenomena’ and ‘effect’ can often serve as synonyms, yet they point in different directions. Phenomena remind us, in that semiconscious repository of language, of events that can be recorded by the gifted observer who does not intervene in the world by who watches the stars. Effects remind us of the great experiments after whom, in general, we name the effects: the men and women, the Compton and Curie, who intervened in the course of nature, to create a regularity which, at least at first, can be seen as regular (or anomalous) only against the further background of theory. (Hacking 1983, 224-225)

Effects require carefully planned production conditions. According to Hacking, the aim of experiments is to “create,” “refine,” and repeat the effects produced in an experiment (1983, 229-230). But because effects fall apart when conditions are modified, it is likely that effects are only produced under *specific* conditions in an experimental setting (1983, 225-226). Suppose that we apply robustness analysis to a given effect to figure out if it is reliable. We develop independent methods for the production of this effect, but because effects are sensitive to conditions, convergence is unsuccessful. What can we conclude about reliability? Using diverging results will not help. It has been argued that divergence or “discordance” in results thwarts useful inferences about reliability and error (Stegenga 2009). An important methodological and epistemological question arises for robustness analysis: *If effects require careful experimental production and are sensitive to changes, how do we know when an effect is genuine, rather when it is a result produced in error (an experimental artifact)?*

In this discussion I argue that robustness analysis does not reliably differentiate between effects and experimental artifacts, but that we can modify its function in such instances to give us useful information about the production relation. In Section 2, I argue that robustness analysis fails to differentiate genuine effects from artifacts because: 1) “Arrangements” cannot be differentiated into the “real” and the artificial; and 2) Introducing multiple methods will change the conditions, thus producing diverging results. In Section 3, I argue that to bypass this problem about differentiating effects from artifacts, we can re-frame the role of robustness analysis. I propose that we can use cross-comparison to understand *how* changes in conditions alter given effects. This allows us to understand the experimental production *process*.

**2. Differentiating Effects from Experimental Artifacts.**

In this section I argue that both effects and experimental artifacts are condition-sensitive, and for this reason difficult to distinguish. Hacking illustrates the condition sensitivity of effects by describing the original Hall effect experiment, where an electric current is passed through a gold leaf in the presence of a perpendicular magnetic field. These conditions produce a potential difference across the conductor (the leaf) and at right angles to the magnetic field and conductor (1983, 224). Hacking says that even though the conditions were carefully planned and the apparatus was human-made, we have the intuition that the phenomenon was “discovered” in the laboratory rather than created (1983, 225). But according to Hacking, the “arrangement” of conditions behind the Hall effect only occurs in the laboratory. He says, “I suggest, in contrast, that the Hall effect does not exist outside of certain kinds of apparatus. Its modern equivalent has become technology, reliable and routinely produced. The effect, at least in a pure state, can only be embodied by such devices” (1983, 225). Hacking’s analogy between technological effects and experimental effects provides an important point. Both types of effects are sensitive to the manipulations of the arrangement of conditions. Kroes (2003) provides a useful characterization that supplements Hacking’s analogy between experiment and technology, and he uses it specifies ‘experimental artifacts’.[[7]](#footnote-7)

Kroes (2003) characterizes ‘artifacts’ in general as resulting from intentional human action and directed toward a specific function. However, he points out that artifacts “obey the so-called laws of nature; that is, their behavior can be explained causally in a nonteleological way” (2003 19). We can summarize Kroes’ (2003) points into two important features of artifacts: 1) Human design/specified function; and 2) Regularities explainable by laws of nature. Kroes’ (2003) initial characterization focuses on technological artifacts, which require a considerable element of human structural design and function. For example, the structured interactions of thin film transistors (TFT’s) can be manipulated for the purposes of LED technology (Machrone 2013).[[8]](#footnote-8) I add that such technological artifacts often result from experimentally produced effects.[[9]](#footnote-9) If technological artifacts are products of human design then experimental artifacts can be characterized as design products of the apparatus and the arrangement of measurement conditions. Kroes (2003) makes a fine-grained characterization of experimental artifacts by discussing “artificial environments” vs. the “object system” of study. Drawing on Franklin’s (1986) discussion he characterizes experimental artifacts as “results that are generated by the artificial environment or artificial means of observation of the natural phenomena under study” (2003, 71). In his discussion of distinguishing artifacts from genuine effects he suggests:

The results of an experiment are always the outcome of the object system interacting with an artificial environment, and therefore it is always necessary to filter out the component in the results that tells us something about the object system. (2003, 71)

While this suggestion is useful in distinguishing phenomena from artifacts, it is not helpful for distinguishing effects from artifacts. The reason why is because it assumes that we can filter out the error in an experimental arrangement by separating the artificial environment from the object system. Sometimes, experimental arrangements do not lend themselves to filtering because they heavily rely on the manipulation of total conditions rather than on the distinction between artificial and natural conditions. Take Hasok Chang’s (2004) discussion the manufacturing process of fixed points in thermometry.

Chang details how the boiling point of water varies with differences in atmospheric pressure and dissolved gas (Chang 2004, 15-19). Different arrangements of conditions will produce a different boiling point. The effect of boiling point is so sensitive to the manipulation of conditions that water can boil at 101.9 degrees C merely in the presence of dissolved gas (Chang 2004, 19). In the history of fixed points like the boiling point of water, material conditions have to be fine-tuned to “manufacture” fixity (2004, 49). Here, Kroes’s (2003) suggestion to filter out the “artificial environment” and focus on the “object system” is not helpful. In the case of boiling point, all we have is “arrangements” that are manipulated. Sometimes nature manipulates the same effects that scientists create in the lab. For example, Hacking says, “If anywhere in nature there is such an arrangement, with no intervening causes, then the Hall effect occurs” (1983, 226). So we can’t claim that some arrangement themselves are artificial and some are natural. Additionally, in the lab, differentiating which arrangements are artificial and which ones are natural is just as difficult. Suppose that we manipulated atmospheric pressure but let dissolved gas run out naturally. While the former requires human intervention it is unclear if it is artificial. The latter requires no human intervention but is still changing given the conditions in the room. In both instances there is a change in conditions relevant to the production of the effect, but the division between artificial and object system is unclear. Perhaps multiplying production methods will help.

A common specification in robustness analysis is to use multiple *independent* methods.[[10]](#footnote-10) Suppose that we want to check to see if water boiling at 101.9 degrees C is an artifact. We repeat the exact same conditions and reproduce the effect of water boiling at 101.9 degrees C. Here, we would not be using independent methods. For example, in our re-production of the boiling point, the physical conditions are the same types of conditions. In fact, because of the sensitivity of boiling point they have to be the same types of conditions to reproduce the same boiling point. If we change the physical conditions, results will diverge from those of our initial condition arrangement. The point is that using independent methods of measurement with sensitive effects will produce diverging results. The divergence does not differentiate effects from artifacts.

The reason why robustness analysis fails to differentiate effects from artifacts is important. In the context of “discovered phenomena,” condition sensitivity is precisely the indicator in robustness analysis that tells us when something is produced in error. The mesosome is an example of a cellular structure that appeared in multiple types of microscopy measurement methods. But it was later found to be a result produced in error by chemical fixation in a specific preparatory procedure.[[11]](#footnote-11) In the context of the mesosome, as soon as we switch preparatory procedures the mesosome disappears (Rasumussen 1993; 2001). This indicates that it was a result produced by the preparatory procedure. In the context of so-called arsenic-ingesting bacteria, as soon as we carefully “wash” the DNA structure we see that there is no covalently bound arsenate in the DNA sample, and so the bacteria does not replace phosphorous with arsenate in its DNA structure (Reaves et al. 2012). This indicates that the pre-spectroscopy DNA “purification” procedure produced the result. In these contexts there is a phenomenon that is *independent of the arrangement of conditions in the preparatory procedures*. In the case of effects, the thing produced is arrangement-dependent. Given that artifacts are arrangement-dependent also, we need another condition that differentiates that two. But instead I propose that we look past the distinction to learn something unique about robustness analysis in the context of effects.[[12]](#footnote-12) We can use diverging results to understand *how* changes in conditions alter given effects.

**3. Production Analysis.**

How can diverging results provide useful information in the context of effects? Robustness analysis focuses on converge. When using the analysis, we focus on consequences common to several independent methods. But there are two philosophical accounts of robustness analysis that say something useful about diverging results (Weisberg 2006; Keyser 2016). I take elements from each in order to develop ‘production analysis’.

Weisberg (2006) focuses on predictions rather than consequences and models rather than methods, but we can modify his steps to be useful for experimental production. Weisberg outlines robustness analysis using four steps. First, we find a robust property, which consists of finding a property, experimental result, or prediction that is common to a set of models with different idealizing assumptions (2006, 736). In the context of effects, we do not *discover* robust properties. Rather, we *produce* certain regularities. As was presented in Section 2, because of the sensitivity of effects and the requirement of independence, effects will fail to converge between production methods. Weisberg’s (2006) second step is to investigate the “common structure” by looking at the common features of the models that give rise to the robust property (2006, 737).” In the context of effects, we can look at this as the common features of production that create a given effect. However, if we have diverging results this step is not useful. The third step is an “empirical interpretation” of the mathematical structures from step two. That is, according to Weisberg in the third step of robustness analysis we are concerned with “interpreting the mathematical structures as descriptions of empirical phenomena (2006, 738).” This step is uninformative for produced effects because we are not using modeling methods to link a theory to a natural phenomenon, but rather we are using experimental methods to manufacture the effect itself. In the context of effects, our concern is a *production relation* rather than a representation relation. However, the final step of Weisberg’s (2006) analysis is important. Weisberg says, “Finally, the theorist can conduct stability analysis of the robust theorem to determine what conditions will defeat the connection between common structure and robust property” (2006, 738).

We can transform Weisberg’s stability analysis into what I call a ‘production analysis’. Instead of looking at what model conditions will defeat the robust property, we can look at *how* specific experimental conditions produce differences and similarities in effects. This requires structuring production analysis into features. First, multiple methods of production are involved. These can be referred to as ‘production processes’. The production processes will contain experimental conditions (i.e. “arrangements”) that are causally relevant to the effects they produce.[[13]](#footnote-13) These methods do not have to be independent. For example, we can compare multiple production processes of the boiling point of water, using the same condition parameter values. In fact, when it comes to effects, it may help to have both dependent and independent methods. The reason why is because we can track what kinds of changes occur from similar processes as well as what kinds of changes occur from different processes. Second, conditions in production processes are compared to map out convergence and divergence. It may be that all production processes diverge (or converge), or that there is a mix of convergence and divergence. This feature of production analysis contains not only a comparison of convergence and divergence but also a comparison of the *conditions* in each production process. Third, theory is applied to the two levels of comparison to explain why certain conditions produce (or fail to produce) specific changes in the effect. This final component of production analysis is informative about *how* conditions change effects. To detail how production analysis works, we can draw on elements from Keyser’s (2016) discussion about cross-comparison and theory in robustness analysis.[[14]](#footnote-14)

For his account of robust measurement, Keyser (2016) assumes an important mechanism discussed by Woodward (2003). Manipulating one variable to see changes in another is causally informative. Keyser (2016) argues that theory in the presence of diverging measurement results can explain *why* divergence occurs. He uses the example of mixed convergence and divergence in multiple modes of temperature measurement. When multiple thermometers converge but others diverge, theory steps in to analyze the conditions behind the divergence (Keyser 2016, 10). Keyser proposes that theory homes in on specific physical differences in thermometers—e.g., the liquid used in a given thermometer—in order to explain how those features produce differences in results (2016, 10-11). This differential comparison and explanation process is useful for measurement in terms of specifying the “location” of error (Keyser 2016, 11). But in the context of production, what does it mean to have an explanation about why divergence occurs?

To be more informative, I add that diverging results can provide information about *which* conditions produce a change (or fail to produce a change) in the effect. In other words, divergence *locates specific changes* in the production relation between condition and effect. Then theory can be used to explain *why* those production changes occur. Suppose that there are two experimental setups (or production processes) for the boiling point of water. In the first setup, there is no presence of dissolved gas. In the second setup, we add a certain amount of dissolved gas, which increases the temperature by a certain amount of degrees. Comparing the two setups in terms of divergence and also in terms of their conditions, we see that there is divergence in results and that the difference in conditions is in the presence of dissolved gas. Each production process creates two different boiling points. Without the presence of theory these comparisons are uninformative. But with the presence of theory we understand that the difference between the two production processes can be explained by a specific theoretical reason (e.g., we are influencing “vapor pressure” in different ways in each process).

To summarize, production analysis requires: 1) Two levels of comparison, which locate what conditions are relevant to the effects. Effects are compared to see the presence of divergence and convergence. Conditions are also compared to see what differences may be responsible for changes (or failures of change) in effects; 2) Theoretical explanation about why divergence is being produced and what conditions are responsible. In production analysis the focus is on how certain conditions produce effects. The aim is to understand *production relations* in the context of multiple production processes. The benefit of production analysis is it provides useful information about the production process without first having to differentiate effect from artifact.

**4. Concluding Remarks.**

While robustness analysis is informative for the distinction between phenomena and results produced in error, it fails to distinguish experimentally produced effects from artifacts. The reason why is because in the context of production, both effects and artifacts are sensitive to changes in methods of production. This means that diverging results will not be informative for differentiating effects from artifacts. Condition sensitivity is precisely the indicator in robustness analysis that tells us when something is produced in error; and both effects and artifacts sound off this indicator. I argued that to bypass this problem about differentiating effects from artifacts, we can re-frame the role of robustness analysis to focus on: 1) Cross-comparison between results and also between conditions; and 2) Theoretical explanation of that cross-comparison. I refer to this process as ‘production analysis’. I proposed that we use diverging results to understand *how* changes in conditions alter given effects. This provides information about the production relation and a new role to robustness analysis in accounting for how conditions are relevant to effects.

**References**

Cartwright, N. 1991. “Replicability, Reproducibility, and Robustness – comments on

Harry Collins.” *History of Political Economy* 23: 143–55.

Chakrabarty, Manjari. 2012. “Popper's Contribution to the Philosophical Study of

Artifacts.” In: *[2012] Philosophy of Science Assoc. 23rd Biennial Mtg (San*

*Diego, CA) > PSA 2012 Contributed Papers*.

Chang, Hasok. 2004. *Inventing Temperature.* Oxford University Press.

Culp, S., 1994. “Defending Robustness: The Bacterial Mesosome as a Test Case.” in

D. Hull, M. Forbes and R. Burian (eds.), *PSA 1994*, East Lansing: Philosophy of Science Association, 47–57.

Douglas, Heather. 2004. “The Irreducible Complexity of Objectivity.” *Synthese*

138(3): 453-473.

Franklin, Allan. 1986. *The Neglect of Experiment*. Cambridge, Massachusetts: MIT Press.

———1997. “Calibration.” *Perspectives on Science* 5:31-80.

Glymour, Clark. 1980. *Theory and Evidence*. Princeton, NJ: Princeton University

Press.

Hacking, I. 1983. *Representing and Intervening*. Cambridge: Cambridge University

Press.

Horwich, Paul. 1982. *Probability and Evidence.* Cambridge: Cambridge University

Press.

Hosono, H., Hirano, M., Ota, H., Kamiya, T., Nomura, K. 2005. “Amorphous Oxide And

Thin Film Transistor.” *US Patent App* 10:592.

Hudson, R. G., 1999. “Mesosomes: A Study in the Nature of Experimental

Reasoning.” *Philosophy of Science* 66:289–309.

Keeley, Brian. 2002. “Making Sense of the Senses: Individuating Modalities in

Humans and Other Animals.” *The Journal of Philosophy* 99(1): 5-28.

Keyser, Vadim. 2016. “A New Theory of Robust Measurement.” *American Philosophical*

*Association 2016 Pacific Division Meeting*. Pre-print:

http://www.apaonline.org/members/group\_content\_view.asp?group=110424&id= 476093

Kroes, Peter. “Physics, Experiment, and the Concept of Nature.” In Radder, Hans, ed..

2003. *The Philosophy of Scientific Experimentation*. Edited by Hans Radder.

University of Pittsburgh Press.

Levins, R. 1966. “The Strategy of Model Building in Population Biology.” *American*

*Scientist* 54: 421–431.

Lloyd, E. A. 2010. “Confirmation and Robustness of Climate Models.” *Philosophy of*

*Science* 77, 971–984.

Lloyd, E. A., Parker, W. 2009. “Varieties of Support and Confirmation of Climate

Models.” *Proceedings of the Aristotelian Society* lxxxiii: 1467-8349

## Machrone, Bill. 2013. “Powering the Resolution Revolution.” *The Wall street Journal*.

## <http://online.wsj.com/ad/article/vision-igzo>

Perrin, J. 1913. *Les Atomes*. Paris : F. Alcan. (Atoms. by D. Li. Hammick, Trans.,

1916). New York: D. Van Nostrand. (Reprinted Kessinger Publishing, 2007).

Rasmussen, N. 1993. “Facts, Artifacts, and Mesosomes: Practicing Epistemology

with the Electron Microscope.” *Studies in History and Philosophy of Science* 24: 221–265.

———2001, “Evolving Scientific Epistemologies and the Artifacts of Empirical

Philosophy of Science: A Reply Concerning Mesosomes.” *Biology and Philosophy* 16: 629–654.

Reaves, M.l., Sinha, S., Rabinowitz, J.D., Kruglyak, L. Redfield, R.J. 2012. “Absence

of detectable arsenate in DNA from arsenate-grown GFAJ-1 cells.” *Science* 337(6093):470-3.

Sober, Elliot. 1989. “Independent Evidence About a Common Cause.” *Philosophy of*

*Science* 56: 275-287.

Staley, Kent. 2004. “Robust Evidence and Secure Evidence Claims.” *Philosophy of*

*Science* 71:467-488.

Stegenga, Jacob. 2009. “Robustness, Discordance, and Relevance.” *Philosophy of*

*Science* 76: 650-661

——— 2012. “Rerum Concordia Discors: Robustness and Discordant

Multimodal Evidence.” in *Characterizing the Robustness of Science* Boston Studies in the Philosophy of Science, Springer, 207-226.

Trout, J.D. 1998. *Measuring the Intentional World*. Oxford: Oxford University Press.

Weisberg, Michael. 2006. “Robustness Analysis.” *Philosophy of Science* 73, 730–

742.

Woodward, J. 2003. *Making things happen: A theory of causal explanation*: Oxford

University Press, USA.

——— 2006. “Some Varieties of Robustness.” *Journal of Economic Methodology*

13:2, 219-240.

Wimsatt, William. 2007. *Re-engineering Philosophy for Limited Beings: Piecewise*

*Approximations to Reality*. Cambridge: Harvard University Press.

1. See Levins (1966); Glymour (1980); Weisberg (2006); and Wimsatt (2007). [↑](#footnote-ref-1)
2. See Horwich (1982); Hacking (1983); Franklin (1997); Sober (1989); Cartwright (1991); Trout (1998); Culp (1994); Woodward (2006); Stegenga (2009). [↑](#footnote-ref-2)
3. In this discussion I use ‘artifact’ in reference to experimental artifacts, which are results produced in error. Technological artifacts will not be addressed except for in the development of a characterization of ‘experimental artifacts’ in Section 2. [↑](#footnote-ref-3)
4. Levins and Wimsatt explicitly characterize common consequences and robust theorems in relation to the modeling process. Here, I extend ‘consequences’ to any method of indentification. [↑](#footnote-ref-4)
5. In discussions about the robust theorem, Weisberg (2006) places attention on underlying common structure. Levins (1966) and Wimsatt (2007) discuss the falsifying idealizations. [↑](#footnote-ref-5)
6. Often, Hacking uses ‘phenomena’ for ‘effects’. [↑](#footnote-ref-6)
7. Kroes’s (2003) is noteworthy because it is an extension of Hacking’s argument for experimentation. Chakrabarty (2012) provides an important summary of definitions of artifacts. [↑](#footnote-ref-7)
8. This technology is based on the Hosono et al. (2005) research on crystal structure. [↑](#footnote-ref-8)
9. Hosono et al. (2005) found that by manipulating the crystal structure of certain materials we can experimentally produce a compound that conducts electricity. The reason why this is an experimental effect is because even if a given compound’s conductivity is low (e.g., due to the asymmetry in the crystal structure), adding titanium atoms to its structure produces symmetric cages, which allows free electron flow (Hosono et al. 2005). [↑](#footnote-ref-9)
10. Philosophers such as, Nagel (1939); Horwich (1982); Franklin (1984); Sober (1989); Trout (1993); Culp (1994); Keeley (2002); Staley (2004); Douglas (2004); Novack (2007); Wimsatt (2007); and Stegenga (2012), have discussed conditions defining independence. I will not summarize the differences in views here. [↑](#footnote-ref-10)
11. For debate on measurement methods and the mesosome see Culp (1994), Rasmussen (1993; 2001), and Hudson (1999). Stegenga uses this example to illustrate converging results can support false conclusions (2009, 653). [↑](#footnote-ref-11)
12. In the remainder of the discussion I use ‘effects’ only in reference to things produced by the arrangement of experimental conditions. [↑](#footnote-ref-12)
13. A particular theory of causation is not important for our purposes. [↑](#footnote-ref-13)
14. Cited with permission from author. [↑](#footnote-ref-14)