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S.I. : FIRST PRINCIPLES IN SCIENCE

Introduction: first principles in science—their status and justification

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1 Introduction

First principles are the fundamental building blocks of every science. Depending on the case, they can be formal axioms, theoretical postulates, basic propositions, or general principles that have a special status and role to play in the theory in which they are embedded. Probably the most prominent cases of first principles are to be found in physics. Newton's laws of motion or Einstein's light postulate and equivalence principle are examples of such fundamental principles that Newtonian mechanics and the special and general theory of relativity, respectively, are built upon. But examples of such principles can be found in other disciplines as well. Prominent examples are the rationality principle in economics or the principle of natural selection in biology. For a long time, scientists and philosophers have debated the status and function of these principles, having been regarded from 'absolute truths,' empirical generalizations, conventions, or mere heuristics. Scholars have given justifications for why they considered them important for generating knowledge yet others again have given arguments for why such principles cannot be justified at all.

While taking place in a number of sciences, philosophical discussions about the status and function of first principles have focused largely on the natural sciences. For example, philosophical debates around Henri Poincaré's conventionalism or Reichenbach's relativized a priori are usually grounded in case studies from physics. While those discussions have provided important insights for our understanding of the status of first principles, they have largely left disciplines other than physics aside, leading to a limited perspective on the different ways in which scientists think about principles. First principles occupy an equally important, yet controversial, role in other natural sciences, the social sciences, and the life sciences. In those disciplines, the

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status of first principles and their epistemic role raises similar concerns. For example, it has been widely discussed that economic theories rest upon first principles of human behaviour that have long been fiercely defended by economists and justified in various different ways. At the same time, they have been attacked and in some cases been replaced. However, those discussions have not yet entered the mainstream philosophical literature on first principles.

This special issue originates in an interdisciplinary workshop entitled ‘First Principles in Science: Their Epistemic Status and Justification’ held at the Munich Center for Mathematical Philosophy at Ludwig-Maximilian-University of Munich, Germany, in 2016. The main set of questions addressed at the workshop centred around disciplinary differences in thinking about the epistemic status of first principles in science and their justifications. In order to approach the debate from different disciplinary perspectives, we brought together philosophers of science, historians of science, and scholars doing integrated history and philosophy of science that focus on a variety of fields. Most papers in this special issue have resulted from this workshop and together provide a rich and representative collection of cases from several research fields. These contributions offer a starting point for further reflection on the topic in a plurality of scientific fields and give us momentum to explore further the status and function of first principles looking beyond the physical sciences.

The contributions in this special issue expand the traditional debate beyond first principles in physics. They do so with respect to two sets of issues. Some contributions engage directly with the philosophical debate on the epistemic status of first principles in science. Other contributions explore the status and nature of such principles in fields such as biology, chemistry, economics, physics, and cognitive science. This introduction offers a summary of the main insights of each contribution and identifies some key commonalities and differences across the various fields with respect to both sets of issues.

2 A sketch of the history of the debate in philosophy of science

The problem of justification of scientific principles has been debated systematically in philosophy of science for over a century. The primary focus of this debate has been the status of the principles of relativity theory, and the status of geometry in physical theories. The debate goes back to the work of Poincaré (1902), who identified the laws of motion and Euclidean geometry in Newtonian mechanics as constitutive conventions, departing from Immanuel Kant’s understanding of these principles as synthetic a priori. Developing this trend further, Reichenbach (1920) introduced the concept of relativized a priori, arguing that some principles, such as the light postulate in the special theory of relativity, play a special epistemic role in the derivation of empirical content of the theory by being constitutive without being absolute, unrevisable truths.

Friedman (2001, 2010) has revived this work and illustrated how we can develop these insights further by construing the principles as playing the role of a priori knowledge in a theoretical framework, whilst also allowing the principles to change, thus taking them to be relativized a priori.[1] Friedman has illustrated this epistemic framework with a detailed study of Newtonian mechanics and the special and general theory of relativity, illustrating, for instance, how before we can meaningfully talk about testing Newton's law of gravity, we need to define what we mean by inertial motion, mass, acceleration, 'straight line'. Such definitions are provided by Newton's three laws of motion in conjunction with Euclidean geometry, that together act as constitutive principles in the Newtonian framework.

In parallel Stump (2015) has developed a pragmatic account of constitutive principles in science. Yet Stump has drawn different philosophical lessons by analysing its historical evolution in understudied pragmatists. Both neo-Kantians like Friedman, and pragmatists, like Stump aim to explain the special status of fundamental principles in light of their historical evolution, acknowledging that first principles can be dynamic and their epistemic status can change in theoretical transitions. These accounts depart in the role they assign to meta-considerations in the adoption of a particular framework, with Friedman placing an important role for philosophical and conceptual discourse in the acceptance of frameworks and their first principles. The pragmatist account has been further enriched by the pluralist perspective on principles developed by Chang (2008). A number of collections have also engaged with the concept of constitutive/functional/relativized notion of a priori principles (Domski et al. 2010; Suárez 2012; Ivanova and Farr 2015).

Apart from the debates in general philosophy of science, questions around the epistemic status and role of first principles also took place within the context of philosophical and methodological debates in science. In some particular disciplines, such as biology, chemistry, or economics, scientists have even debated whether they can meaningfully talk about first principles at all. For instance, for a long time one major topic among economic methodologists such as Lionel Robbins, Ludwig von Mises, or Terence Hutchinson, was whether first principles in economics like the rationality principle or the principle of scarcity have the same status as the first principles in physics describing the movement of physical objects. Such debates have been taken up in philosophy of economics and discussed by prominent philosophers of economics (e.g., Hausman 2010; Rosenberg 1976; Maki 2001). However, they have only partially been informed by the different views that have been brought forward in general philosophy of science. Integrating both debates can inform philosophical accounts of the nature and role of first principles in fields other than physics and illuminate disciplines where the very question of whether first principles are even possible is a matter of debate.

3 Summary of contributions

The issue includes discussion of scientific principles in economics (Herfeld, Hoover, Linsbichler), chemistry (Hendry), biology (Luchetti, Okasha), cognitive science (Colombo), and physics (Crowther). In this section, we summarise what we found

[1] Note that in different contexts, Michel Foucault's and Ian Hacking's notions of the 'historical a priori' play an analogous role, i.e., the historical a priori is constitutive with respect to new kinds of propositions coming into being as having truth conditions (e.g., Foucault 1969, 1994 [1966]; Hacking 1982, 2002).

to be the most interesting points in these contributions in order to draw some lessons from this interdisciplinary engagement that we hope will form a useful guide in the future development of the debate.

The discipline of economics is a case in point where the status and function of first principles have long been discussed but where debates were largely disconnected from the philosophical literature. Kevin Hoover's paper entitled "First Principles, Fallibilism, and Economics" examines a tension in the history of economics that reflects primarily on the methodological discussions in economics. The tension arises from a simultaneous commitment to fallibilism, and to an empiricist program on the one hand, and to foundationalism, and the view that deductive reasoning has to start from infallibly true or indubitable first principles, on the other hand. Hoover shows that we can see this tension when we consider the connection between the definition of economics, economists' conceptions of science, and the role that first principles played in their methodologies. It arises in three cases that Hoover discusses: John Stuart Mill's definition of economics as the science of wealth, Lionel Robbins' definition of economics as constrained optimization, and Gary Becker and Georg Stigler's reformulation of neoclassical economics that attempted to square empiricism with deductivism.

We learn from those cases how economists, while often taking physics as their methodological role model, would seek refuge in arguments defending the difference between natural and social sciences when justifying first principles in economics. Mill, whose methodology was for a long time accepted by economists, argued that despite first principles in economics being empirical truths, they are beyond genuine doubt. Part of Mill's strategy to square the deductive character of economics with the view that first principles in economics have empirical status is to assume that we know the truth of those principles—as they concern the desires and behaviour of human agents—by direct acquaintance. Furthermore, by limiting economic behaviour to the desire for wealth, Mill restricts the scope of those principles to market behaviour. For Robbins, economics is defined more broadly in terms of choice, a definition that directly results from a set of behavioural and other first principles, such as scarcity of resources. Unlike in the natural sciences, we come to know principles that govern human behaviour by 'immediate acquaintance' with generally available experience. On Robbins' view, the definition of economics as concerned with choice under scarcity is not referring to its subject matter but rather specifying its framework. As such, while Mill takes those principles to be infallible because testing them is impossible for epistemic reasons, Robbins views those principles—particularly the principle of constrained optimization—as a priori and infallible; they cannot be falsified but only wrongly applied. But on both accounts, the principles are justified a priori. With Becker and Stigler, the key first principles of economics—the principle of constrained optimization and the principle that preferences are stable—are ultimately justified by their pragmatic success in explanations and predictions and as such are supportable by empirical evidence; they are indubitable but fallible.

Recent philosophical accounts of a priori elements in science have stressed the importance of a pragmatic approach to explain conceptual change. For example, David Stump promotes a pragmatic theory of constitutive elements that classifies first principles as functional a priori elements. Herfeld's paper entitled "Understanding the Rationality Principle in Economics as a Functional A Priori Principle" draws on Stump's account to address the question of how, in light of ongoing debates in economic methodology and philosophy of science, we should think about the epistemological status and function of one of the most important, if not the most important, first principles in economics: the rationality principle. She argues that Stump's pragmatic account of principles can explain both why the rationality principle enjoys a special status in economic theorizing, since it has long functioned as an a priori element in almost any epistemic context in economics, and further account for the fact that the rationality principle has undergone several conceptual changes throughout the discipline's historical development as well as across different epistemic contexts.

To capture both kinds of conceptual change, Stump's account is preferable compared to rationalist or empiricist approaches that have long dominated the debate about the status and function of the rationality principle. One specifically advantageous aspect of Stump's account is its broad notion of epistemic 'context.' Context for Stump does not only encompass scientific theories but also other epistemic objects, such as different kinds of modelling techniques, and scientific practices, such as experimentation. The rationality principle has occupied different functions in all those contexts. This view serves well in the social sciences since they rarely operate with one general scientific theory.

With the rise of behavioural economics as a serious rival to neoclassical economics and to alternative schools such as Austrian economics, the debate about the nature, status and function of first principles in economics has become prevalent again. Herfeld shows in which way the rationality principle has occupied a special status in almost any area of orthodox economics where a long-standing rationalist tradition has led to its justifications as an a priori element of economic theory. A defender of the most extreme form of rationalism has probably been Ludwig von Mises, a representative of the Austrian School of economics and economist with a strong influence on Robbins. Alexander Linsbichler's paper "Austrian Economics without Extreme Apriorism—Construing the Fundamental Axiom of Praxeology as Analytic" offers a reinterpretation of von Mises' well-known apriorism by discussing the role and epistemological status of the so-called "fundamental axiom" of von Mises‘ praxeology, a variant of the rationality principle. The axiom 'man acts,' has been famously justified by von Mises as the a priori true starting point of all economic theorizing. Within but also outside the Austrian school its justifications have included invocations of pure intuition, pure reason, rationalist introspection, or evolution. Mises himself has often been portrayed as a Kantian or Neo-Kantian, claiming for the axiom the status of a synthetic a priori element.

The status of this fundamental axiom has been fiercely debated and led to the rejection of praxeology as a research program by the economics profession at large. Linsbichler tackles this important issue with an innovative solution by offering a conventionalist justification for the axiom. If successful, such a justification would support a moderate aprioristic reading of praxeology and could help overcome the existing trenches between different economics schools that have so far not been easy to overcome. It would also enable a discussion with contemporary philosophy, which has largely rejected the idea of synthetic a priori statements. Linsbichler defends a conventionalist reading of praxeology, arguing that it fulfils a set of conditions that conventionalism requires: first, that conventions could have in principle been chosen differently; and, second, that conventions are not justified by intuition or observation but rather by pragmatic considerations that aim at the superior expediency of praxeology as a research program. Thereby, Linsbichler proposes a justification of the axiom as a linguistic convention, which requires rethinking its justification as a synthetic a priori element and rather justify it as an analytic element, true in virtue of meaning. Linsbichler further argues that analyticity of the fundamental axiom does by no means imply the empirical uselessness of praxeology; a conventionalist praxeology and a pragmatic justification of the fundamental axiom are compatible with realist and anti-instrumentalist positions.

Like the rationality principle, one key principle of chemical composition has been that elements are actually present in their compounds. In his paper entitled "Elements and (First) Principles in Chemistry," Robin Hendry labels this principle 'Actually Present Elements', traces it throughout the history of chemistry, and discusses its epistemic status. Hendry argues that although the facts making the principle true were only discovered during the twentieth century, the principle has played a central role throughout the history of the compositional research program in chemistry even before the chemical revolution. In discussing Lavoisier, Dalton, Mendeleev, and up to the early twentieth century, Hendry argues for the continuous explanatory role of elements and a stable concept of element persisting throughout this history. He argues that the best way to understand the status of this principle is as a metaphysical assumption, which frames the scientific activity before it becomes empirically supported in the context of a scientific theory.

One pressing question in philosophy of science has been how metaphysics can be reconciled with a realist account of science. For such an account to be plausible, Hendry considers a set of conditions: first, metaphysical theories or claims have to be considered as factual claims; second, their role should not be merely psychological. Rather, in order to fulfil their regulative and heuristic role in science in supporting realist inferences, those roles should depend upon the content of the metaphysical principle. And third, the role of such metaphysical principle should be appraisable in the same way as abstract scientific principles are credited for the empirical success of the theoretical developments of which they are part. Hendry explores several accounts that aim to explain the role of metaphysical principles in science, as developed by Karl Popper, J.W.N. Watkins, Imre Lakatos and Elie Zahar, to endorse the latter. Zahar's account supports the idea that metaphysical principles offer 'prescriptive import' on the structure of physical laws and explanations.

Turning to biology, in his "The Strategy of Endogenisation in Evolutionary Biology," Samir Okasha illustrates through a variety of examples how evolutionary theory increased its explanatory power by subsuming within its explanatory scope theoretical assumptions that were originally postulated without receiving an explanation. Okasha illustrates this observation by introducing the principle of endogenisation—identifying features or presuppositions that were originally part of the background of assumptions of evolutionary theory and with time became themselves explained by it. Okasha identifies several such successful endogenisations within evolutionary theory: the origin of variation, anisogamy, altruism and social evolution, niche construction, hierarchical organisation, and the genotype–phenotype map. For example, anisogamy refers to the evolutionary differences between sexes in species like ours, where the organism's reproductive cells (gametes) are different in females and males. While this difference was presupposed but not explained originally by sexual selection, currently there are several explanations entertained within evolutionary biology to account for anisogamy. This shows the principle of endogenisation at work.

Okasha argues that as evolutionary theory advances, several such features changed their status, from presuppositions on which the explanations provided within the theory were built, to themselves becoming a feature for which an explanation was needed. By focusing on the strategy of endogenisation, we can understand the ability of evolutionary theory to unify a diverse range of phenomena and to increase its explanatory content over time. The unification proceeds by identifying theoretical assumptions that with the progress of evolutionary theory have changed their status and role from unexplained presuppositions to themselves receiving explanation by the theory.

Starting with the classic debate on the relativized a priori, Michele Luchetti's paper "Constitutive Elements in Science Beyond Physics: The Case of the Hardy–Weinberg Principle" aims at extending Friedman's framework beyond the physical sciences and illustrating how the very notion of constitutivity of principles can be a matter of degree and context. Luchetti's goal is to overcome one of the key shortcomings of Friedman's account, namely its focus and applicability to space–time theories in physics. While Friedman's account of relativized a priori principles seems plausible in the cases of space–time theories, it is not as clear whether such layered approach to scientific theories can be had outside of physics. This holds especially for sciences that are not mathematized and do not use a formal framework to formulate their theoretical content. Luchetti aims to make the 'gradualism' implicit in Friedman's work more explicit and give it a general application. The idea is that some elements (such as the calculus) are more constitutively a priori than other elements, such as mechanical laws, but they together enable the formulation of the empirically testable law of gravity. To achieve both aims, Luchetti proposes that we identify three common features of constitutive principles: (1) quasi-axiomaticity, which describes the property of conventions that are essential and fixed and that provide standards for investigation of a particular domain; (2) generative potential, referring to the asymmetric relationship between the purely empirical content of theories and the constitutive principles on which the former depend for their possibility; and (3) empirical shielding, referring to the fact that the more general a constitutive element is, the harder it is to empirically test it. Luchetti takes these features to be exemplified to a different degree by constitutive principles in different theoretical frameworks. He illustrates the flexibility of this account with the case study of the Hardy–Weinberg principle in population genetics, showing how the principle meets the three features of constitutivity by acting as an enabling condition and identifying what real situations need to be accounted for within the framework.

In their contribution "First Principles in the Life Sciences: The Free Energy Principle, Organicism, and Mechanism," Matteo Colombo and Cory Wright analyse the role of the free energy principle in biological systems (FEP) and its epistemic justification. The FEP has successfully been used as a fundamental principle in biology and neuroscience in particular. It applies to diverse levels of biological systems—from single-cell organisms to social networks—and states that any self-organising system that maintains its physical integrity over a relatively long period of time must minimise its expected free energy. While the principle was first proposed to explain how causal regularities are picked out by perceptual processes from sensory data, the current application of the principle goes beyond perception, learning and action, and is used to understand the evolution and development of organisms. The authors argue that the principle allows for the understanding of the relationship between the environment, the brain and the body, acting as a fundamental principle, and they grapple with how its status should be construed. FEP is an axiomatic first principles approach to the life sciences. The principle acts as a precondition for the existence of adaptive systems in the sense that adaptive systems are only possible in light of the principle being true.

The authors also discuss the relationship between the FEP approach and two opposing approaches to how phenomena in the life sciences should be understood: either by appealing to organisms and their respective functions/principles of biological autonomy as well as their adaptivity, which is called organicism; or by appealing to mechanisms, spatiotemporal composite systems producing the phenomenon, an approach that is called mechanicism. Both approaches are in conflict with the FEP approach, which borrows the formalism of random dynamical systems to explain the behaviour and nature of organisms. So which approach is better fitted to do this job? The authors take a pluralist perspective to this question, arguing that phenomena in the life sciences should be studied using a diversity of approaches, by appealing to axiomatic first principles approach of FEP alongside the analytic and synthetic approaches of the mechanics and organicists respectively.

Much of the discussion on the status of scientific principles has been backward-looking, examining the role and status of first principles within a well-established scientific theory. But an interesting discussion is also taking place in the development of theories of quantum gravity (QG), where the discussion is forward-looking. It centres around the question of what principles will be relevant or desirable in the future development of such a theory. In her paper "Defining a Crisis: The Role of Principles in the Search for a Theory of Quantum Gravity," Karen Crowther outlines several principles that contemporary theoretical physicists want to preserve in a future theory of QG and discusses what roles they play in the process of building a unified theory. Crowther identifies at least five important roles that principles play in the development and justification of a theory in current QG: a principle can (1) serve as a guiding heuristic in the development of a new theory; (2) work as a postulate in the theory; (3) serve as a criterion of acceptance of the theory; (4) serve as a criterion of confirmation of a theory; and, most tangentially, (5) serve as a fallible constraint in the sense that the presence of such a principle in a new theory is desirable, yet not necessarily imposed.

With these roles in mind, the contribution illustrates why there is a crisis in the development of QG: in searching for the unification of general relativity with quantum field theory, there is a disparity of principles between the two theories in the sense that principles of the former are violated in the latter, and vice versa. This conflict needs resolving in the development of a successful unifying theory so an agreement as to which principles need to be retained and used in the development of the theory is needed. Crowther offers a sample of such general principles used in the search of a theory of QG, such as the correspondence principle, UV-completion, background independence and the holographic principle, which the author argues will perform a diversity of functions in the theory, both as heuristics but also as constitutive in the new framework. It is noteworthy that the favourable approach to QG does not develop a new set of principles and thus it is difficult to see the theory transition as a revolutionary process, as it would be construed on Michael Friedman's account. At the same time, the approach to QG that develops a new principle (the holographic principle), has not received empirical support yet. While it is unclear whether we can treat the above-mentioned principles as constitutive in the Reichenbach-Friedman-Stump sense, the author stresses the pluralistic function of principles in this forward-looking investigation.

4 Implications

The contributions to this special issue engage with the current literature on the epistemic status and justification of first principles in science with respect to two sets of issues. Some contributions engage directly with different philosophical accounts, specifically by Poincaré, Friedman, Stump, and conventionalism more generally. Other contributions explore the status and nature of first principles in fields such as evolutionary biology, population genetics, chemistry, economics, physics, and the life sciences. Some papers do both by using a concrete case study to inform a philosophical analysis on the function and nature of first principles in a particular field. Discussing a variety of cases and thereby showing the diversity of first principles in disciplines other than physics is one main contribution of this special issue to the existing literature.

The case studies in this special issue have illustrated the difference in status that first principles can occupy across the sciences. They can act as definitions, presuppositions for theory building and scientific reasoning, unjustified axioms, as metaphysical assumptions that enable a scientific activity, as well as constraints on the future theory development. We have also seen that, given their status, they play different—sometimes rather unexpected—roles. For instance, while in evolutionary biology, they contribute to a gradual reduction of theoretical elements to, and to a broadened scope of Darwinian principles, in economics they were for a long time enabling deductive reasoning similarly to physics yet varied in its functions as economists began to use epistemic tools other than theories.

The contributions have given us insight into the dynamicism of principles, by highlighting how they can change status and role in the evolution of a theory through theory change, and also across different epistemic contexts. A number of contributions have highlighted how an employed assumption that originally lacks empirical support, can over time gain such support and thereby change from an apriori to an empirical element. One question that arises from such cases is whether our confidence in the assumption strengthens if we see such an assumption becoming part of the empirically supported claims in a theory. Does such a change of status of a principle, for instance, from a metaphysical assumption to an empirically supported one, pull us towards scientific realism? At the same time, the reverse occurs as well with well-supported empirical claims being elevated to the status of absolute truths, taking the status of undoubted principles in a theoretical framework. These cases illustrate the pragmatic aspect behind scientists' decisions to elevate certain laws, axioms, and assumptions to principles and our decisions to treat them as if they were absolute truths.

The question about whether there can be absolute truths becomes even more pressing when we consider that the function of a theoretical element depends upon the epistemic context it is used in. In some contexts, such as in modelling, a theoretical element can function as an assumption but in the context of a theory, it can function as an a priori element we presuppose to enable scientific reasoning in the first place. The rationality principle in economics is such a case. In its axiomatic formulation, it provides behavioural assumptions grounding economic models. Yet, in the context of a market theory as is general equilibrium theory, it functions as an unjustified first principle that, together with other principles, enables scientific reasoning about market relations. In such cases, a first principle plays this role qua its status that is in turn pragmatically determined, depending on the problem at hand.

The special issue has also illuminated important parallels in the way different disciplines have construed the function and nature of first principles. For instance, we see discussions taking place in both economics and physics of how first principles are to be understood, with similar accounts emerging, such as a priorism, in both disciplines. However, there also substantial differences between both disciplines. While conventionalism has been a major position defended by philosophers of physics and physicists alike to justify the status of physical first principles, conventionalism as a position was never really on the table for economic methodologists and economists to think about first principles in economics. Contributions in this special issue suggest, however, that some form of conventionalism could be one way to fruitfully cope with the apparent tension between fallibilism and foundationalism that economists have long grappled with.

The contributions also give us insight into the possibility of reduction of first principles in higher level sciences to principles of what is usually construed a more fundamental science, which is an assumption some traditional accounts of a priori principles made (see Friedman 2001). An instance of such reduction would be to reduce the principles of neurobiology or chemistry to those of physics. The fact that oftentimes each discipline employs more than one set of principles makes the job of mapping such content from one level of analysis to the other challenging. Additionally, the dynamicism of these principles and their changing status could pose another hurdle to the reductivist project.

The plurality of perspectives on the status and role of first principles in science presented in this special issue allows us to identify different ways in which principles are used across disciplines. It also helps us recognise that often a variety of principles are employed in one particular field, pushing us to recognise, like Reichenbach, not only that principles are not necessary and absolute truths because they change during theoretical transitions, but also that at the same time, we might choose to operate with more than one set of principles. This opens the door to considering a pluralist perspective and pragmatist perspective on scientific principles. The pragmatist perspective is also reinforced by reflecting on the fact that constitutive elements serve their purpose depending on the scientists' aims. For instance, the way in which economics is defined and the methodology the economy is studied with affects our pragmatic choice of theories and of their constitutive elements, depending on what best serves the problem the economist addresses (see, e.g., Chetty 2015).

Against this background, we see that future discussions of first principles will benefit from an integrative approach and from studying both the history and foundational questions of first principles in specific fields. The historical perspective allows us to consider the positions of scientists themselves. As we have seen, this is crucial in the context of those debates because the justifications of first principles not only spring from trading off various epistemic virtues but also from considerations about conceptual, methodological, and epistemic constraints that scientists face to different degrees in distinct fields. Furthermore, the close analysis of single cases over time also reveals elements of contingency characterizing the status of first principles. We can furthermore place the variety of justifications for the same set of first principles into context, ranging from a changing image of science, the availability of methods of investigation, to the epistemic limitations that a specific subject matter poses for formulating a set of first principles.

By taking an interdiciplinary perspective, we can understand the variety of first principles within and across specific fields to address the question under which conditions and in what way such principles enable the production of knowledge in these disciplines specifically and in science more generally. Whether this diversity undermines the rationality of science is a matter that we will have to continue debating about in the future.

References

Chang, H. (2008). Contingent transcendental arguments for metaphysical principles. In M. Massimi (Ed.), *Kant and the philosophy of science today* (pp. 113–133). Cambridge: Cambridge University Press.

Chetty, R. (2015). Behavioral economics and public policy: A pragmatic perspective. *American Economic Review, 105*(5), 1–33.

Domski, M., Dickson, M., & Friedman, M. (Eds.). (2010). *Discourse on a new method: Reinvigorating the marriage of history and philosophy of science*. Open Court.

Foucault, M. (1969). *The archaeology of knowledge*. New York: Pantheon Books.

Foucault, M. (1994 [1966]). *The order of things*. Vintage Books: New York.

Friedman, M. (2001). *Dynamics of reason*. Stanford, CA: Csli Publications.

Friedman, M. (2010). Synthetic history reconsidered. In M. Domski & M. Dickson (Eds.), *Discourse on a new method*. Chicago: Open Court.

Hacking, I. (1982). Language, truth and reason. In M. Hollis & S. Lukes (Eds.), *Rationality and relativism* (pp. 48–66). Oxford: Blackwell.

Hacking, I. (2002). *Historical ontology*. Cambridge: Harvard University Press.

Hausman, D. (2010). *The inexact and separate science of economics*. Cambridge: Cambridge University Press.

Ivanova, M., & Farr, M. (2015). Conventional principles in science: On the foundations and development of the relativized a priori. *Studies in the History and Philosophy of Modern Physics, 52,* 111–113.

Maki, U. (Ed.). (2001). *The economic world view: Studies in the ontology of economics*. Cambridge: Cambridge University Press.

Poincaré, H. (1902). Science and hypothesis. In S. Gould (Ed.), *The value of science: Essential writings of Henri Poincaré*. New York: The Modern Library.

Reichenbach, H. (1920[1965]). *The theory of relativity and* a priori *knowledge*. Berkeley/Los Angeles, CA: University of California Press.

Rosenberg, A. (1976). *Microeconomic laws*. Pittsburg: University of Pittsburg Press.

Stump, D. (2015). *Conceptual change and the philosophy of science: Alternative interpretations of the a priori*. New York: Routledge.

Suárez, M. (2012). Science, philosophy and the a priori. *Studies in History and Philosophy of Science Part A, 43*(1), 1–6.