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The Standard Model in the History of the Natural Sciences, Econometrics, and the Social Sciences

W P Fisher Jr[1,2]
[2] Principal and Founder, LivingCapitalMetrics.com
5252 Annunciation St, New Orleans, Louisiana 70115 USA

E-mail: william@livingcapitalmetrics.com

Abstract. In the late 18th and early 19th centuries, scientists appropriated Newton's laws of motion as a model for the conduct of any other field of investigation that would purport to be a science. This early form of a Standard Model eventually informed the basis of analogies for the mathematical expression of phenomena previously studied qualitatively, such as cohesion, affinity, heat, light, electricity, and magnetism. James Clerk Maxwell is known for his repeated use of a formalized version of this method of analogy in lectures, teaching, and the design of experiments. Economists transferring skills learned in physics made use of the Standard Model, especially after Maxwell demonstrated the value of conceiving it in abstract mathematics instead of as a concrete and literal mechanical analogy. Haavelmo's probability approach in econometrics and R. Fisher's *Statistical Methods for Research Workers* brought a statistical approach to bear on the Standard Model, quietly reversing the perspective of economics and the social sciences relative to that of physics. Where physicists, and Maxwell in particular, intuited scientific method as imposing stringent demands on the quality and interrelations of data, instruments, and theory in the name of inferential and comparative stability, statistical models and methods disconnected theory from data by removing the instrument as an essential component. New possibilities for reconnecting economics and the social sciences to Maxwell's sense of the method of analogy are found in Rasch's probabilistic models for measurement.

1. Introduction

In the late 18th and early 19th centuries, scientists took Newton's successful study of gravitation and the laws of motion as a model for the conduct of any other field of investigation that would purport to be a science. This early form of a "Standard Model" evolved and eventually informed the quantitative study of areas of physical nature that had previously been studied only qualitatively, such as cohesion, affinity, heat, light, electricity, and magnetism [1]. Referred to as the "six imponderables," scientists in this period were widely influenced in experimental practice by the idea that satisfactory understandings of these fundamental forces would be obtained only when they could be treated mathematically in a manner analogous, for instance, with the relations of force, mass, and acceleration in Newton's Second Law of Motion.

James Clerk Maxwell is known for his repeated use of a formalized version of this analogy in lectures, teaching, and the design of experiments [2, 3]. His electromagnetic theory, in turn, then became the "prototype for all the great triumphs of twentieth-century physics...and for the unified

[1] To whom any correspondence should be addressed.

theory of fields and particles that is known as the Standard Model of particle physics" [4, 5]. Several economists, such as Jevons, Walras, and I. Fisher, employed Maxwell's method of analogy from the Standard Model implicitly [6, 7]. (All subsequent references to the Standard Model here concern the 19th century sense of it described by Heilbron [1], not the 20th century meaning referred to by Dyson [4].) Jan Tinbergen explicitly adopted Maxwell's method as a result of his studies with Ehrenfest and Boltzmann [8, 9].

The Standard Model is the context most appropriate for grasping the importance of the work of Georg Rasch, a student of Tinbergen's colleague and co-Nobelist, Ragnar Frisch, and colleague of Tinbergen's student, Tjalling Koopmans. Rasch presents psychological measurement in terms of an analogy from Maxwell's analysis of Newton's Second Law [10]. The existence of mathematical models, and of results, in the social sciences that are structurally identical with those in the natural sciences, suggests a basis for a fundamental reorientation and reprioritization of methods in psychosocial research, and in any area in which ordinal counts, ratings, or rankings constitute the form of observations that must be evaluated and transformed into linearly invariant measures [11, 12].

2. Theoretical Perspective

The basic concept incorporated in the Standard Model is that each parameter has to be measurable independently of the other two, and that any combination of two parameters has to cause the third to take predictable values. These relationships are demonstrably causal, and are not just unexplained but conveniently reproducible associations. So force has to be the product of mass and acceleration; mass has to be force divided by acceleration; and acceleration has to be force divided by mass.

The ideal of a mathematical model incorporating the kinds of relations found in Newton's second law guided much of 19th century science, and historians of economics and econometrics have documented another line of extensions of the Standard Model. For instance, in Walras' first effort at formulating a mathematical expression of economic relations, he "attempted to implement a Newtonian model of market relations, postulating that 'the price of things is in inverse ratio to the quantity offered and in direct ratio to the quantity demanded'" [7].

Jevons similarly studied energetics, in his case, with Michael Faraday, in the 1850s. Pareto also trained as an engineer; he made "a direct extrapolation of the path-independence of equilibrium energy states in rational mechanics and thermodynamics" to "the path-independence of the realization of utility" [7]. The concept of equilibrium models in econometrics stems from this work, and was elaborated in the analogies Jan Tinbergen drew between economic phenomena and pendulum behavior, following Maxwell's method [9].

With the transition in physics to quantum mechanics [13], the introduction of analysis of variance and covariance, and regression methods by Ronald Fisher [14], and the proposal of probability approach by Haavelmo [15], the Standard Model quietly became statistical. The departure from the practice of science was not noticed in economics and the social sciences because the rhetorical and epistemological values of science conformed better with the new statistical methods than they did with the experimental practices of working scientists [16, 17]. That is, the mutual implication of subject and object that characterizes captivation with meaning and the propagation of inscriptions across media [18-20] was as yet unrecognized as a determining factor in the successful identification and exploitation of scientific capital. Statistical practice therefore assumed the validity of the Cartesian dualist understanding of scientific method functioning at the time as the dominant paradigm, resulting in what has been referred to as an "ontological divide" between ostensibly quantitative methods and qualitative methods focused on the social construction of authentic meaning [21].

The problem, as much for Fisher as for others, such as Thurstone [22], revolved around criteria for objectivity and the associated necessity of selective attention in the choice of legitimate observations (for instance, see Good's [23] brief remark on Fisher's tempestuous outburst in response to a comment in this regard). The same tension between a purely statistical orientation toward models as describing intervariable relationships and a measurement orientation toward models as prescribing intravariable relationships continues in today's debates on methodology [24-26]. But perhaps a criterion distinction capable of commanding a new consensus emerges in the overlap of (a) dissatisfaction with quantitative methods that are mere numerical manipulations and (b) enthusiasm for qualitatively meaningful, applicable, and critical elaborations on ratios of demonstrably invariant comparisons [10, 11, 27-30]. Instead of treating group-level ordinal scores as measures in models that make stochastic assumptions impossible to derive from theory and to apply to individual cases [30. 31], ought not approaches more true to the concept of methodical reproducibility root measurement in requirements derived from theory and applicable to individuals? Instead of making implausible assumptions concerning normality, independence, and linearity, should not these be formulated as hypotheses and subjected to experimental tests? The latter has long in fact been the case in Rasch measurement practice, so let us now turn our attention to it.

3. Discussion

In his 1934-35 studies with Frisch in Oslo and with Ronald Fisher in London, the Danish mathematician Georg Rasch [32, 33] made the acquaintance of a number of Tinbergen's students, such as Koopmans [34], from whom he may have heard of Tinbergen's use of Maxwell's method of analogy, if he did not learn it directly from Tinbergen himself. In Chapter VII of his book [10], after developing the theme under the headings of "2. Maxwell's analysis of the concepts of mass and force" (pp. 110-111), "3. The 'multiplicative law of accelerations'" (pp. 111-113), and "4. Units of mass and force" (pp. 113-114), Rasch employs such an analogy in the presentation of his measurement model, saying

> Maxwell's very detailed analysis, of which this is only an incomplete summary, has greatly fascinated me on finding that the same kind of argument should be applicable elsewhere, in particular in problems of measurement in psychology. (p. 113)

In sections 3 and 4 of the chapter, following Maxwell [35] (sections 45-53 in Chapter Three), Rasch describes the symmetry between mass and force, providing a table noting variations in the amount of force applied by various instruments to various objects of varying masses (p. 114). This table can be ordered in such a way as to display the proportionality of the accelerations obtained in both the rows (masses) and the columns (forces). The multiplicative law of accelerations is then written as

$$A_{vj} = F_j / M_v$$

where the acceleration A is the product of two factors, the force F applied by instrument j divided by the mass of object v. Rasch concludes section 4 by pointing out

> "…the acceleration of a body cannot be determined; the observation of it is admittedly liable to…'errors of measurement', but…this admittance is paramount to defining the acceleration per se as a parameter in a probability distribution—e.g., the mean value of a Gaussian distribution—and it is such parameters, not the observed estimates, which are assumed to follow the multiplicative law [acceleration = force / mass].
>
> Thus, in any case an actual observation can be taken as nothing more than an accidental response, as it were, of an object—a person, a solid body, etc.—to a stimulus—a test, an item, a push, etc.—taking place in accordance with a potential distribution of responses— the qualification 'potential' referring to experimental situations which cannot possibly be [exactly] reproduced.
>
> In the cases considered [earlier in the book] this distribution depended on one relevant parameter only, which could be chosen such as to follow the multiplicative law.
>
> Where this law can be applied it provides a principle of measurement on a ratio scale of both stimulus parameters and object parameters, the conceptual status of which is comparable to that of measuring mass and force. Thus, by way of an example, the reading accuracy of a child…can be measured with the same kind of objectivity as we may tell its weight…" (p. 115).

What Rasch provides in the models that incorporate this structure is a portable way of applying Maxwell's method of analogy from the Standard Model. Maxwell separated the structure of scientific law from the specifics of a direct analogy with any particular law. Rasch, then, adapted the invariance properties associated with statistical sufficiency [36] in a probabilistic context to the demands of the three-part structure of the Standard Model. Just as Maxwell [37] (pp. 159-160) took the properties of a frictionless fluid subject to variation in pressure, volume, and temperature as a model for electricity, so, too, do Burdick, Stone, & Stenner [38] present an example relating a Rasch Reading Law to the Combined Gas Law. Just as Maxwell arrived at a theory capable of demonstrating predictive control over the parameters in the model, so, too, is the Rasch Reading Law shown to conform with the expectations formulated on the basis of a substantive manipulation of the variables affecting text complexity, reading ability, and comprehension rates.

This perspective, that “the best scheme...is the one that makes comprehension the easiest,” dates to the late 18th century and can be traced to the works of Condorcet and Kant [1]. The echoes of Kant's [39] assertion that “reason has insight only into that which it produces after a plan of its own” are unmistakable [40]. The Standard Model provides a simple, parsimonious and elegant plan for facilitating reason's insights. Rasch's appropriation of Maxwell's method of analogy makes that plan available to any interested in employing it.

4. Conclusion

The generalized capacity to design and execute experimental tests of hypothesized lawful regularities in constructs of all kinds suggests the existence of powerful and untapped potentials hidden within psychometrics and econometrics [25, 41]. There is a great need for studies that focus less on statistical hypothesis testing and more on the modeling of constructs, the estimation of values in a shared metric framework, the calibration of instruments of known and appropriately gauged precision, and the dissemination of those instruments for end use applications that provide useful, relevant, and interpretable mass customized quantitative information immediately upon administration. Such an integration of theory and practice would remove the need for many of the cumbersome and inefficient centralized data gathering, analysis, reporting methods currently in use, and would open the door to new efficiencies in human, social, and natural capital markets.

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