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Importance of Mathematical & Statistical Methods in Social Sciences

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Abstract

Over the years, mathematics and statistics have become increasingly important in the social sciences. A look at the history of mathematics quickly reveals this claim. In the beginning of the 20th century most of the theories in the social sciences were formulated in qualitative terms while quantitative methods did not play a substantial role in the formulation and establishment of them. Moreover, many practitioners considered mathematical methods to be inappropriate and simply not suited to foster our understanding of the social domain. Notably, the famous Methodenstreit (Method Dispute) was also about the role of mathematics in the social sciences. Mathematics was considered as the method of the natural sciences from which the social sciences had to be separated during the period of maturation of these disciplines. This is actually changed by the end of the 20th century. By then, mathematical and especially statistical methods were standardly used and it became relatively uncontested that they are of much value in the social sciences. In reality, the usage of mathematical and statistical methods is now ubiquitous. Almost all social sciences depends on mathematical and statistical methods to analyze data and to form hypotheses, and almost all of them use (to a greater or lesser extend) a range of mathematical methods to help us understand the social world.

Introduction

History of Mathematics reveals that whenever a society gave weightage to the knowledge of Mathematics, it made a tremendous progress to the society. When Mathematics makes its contribution in the advancement of science, technology and Society, then society draws huge advantages. A view of its history shows a very good picture of the overall development of our civilization. What we have in the form of mathematical knowledge today is the result of the combined efforts of all human beings. Mathematics is the common heritage of mankind and it is not the exclusive property or proprietary of any particular race or country. So we can say that history of Mathematics is the history of civilization.

Additional indication for the increasing importance of mathematical and statistical methods in the social sciences is the formation of new sub-disciplines, and the establishment of specialized journals and societies. And indeed, sub-disciplines such as Mathematical Psychology and Mathematical Sociology emerged.

The mathematization of economics set in somewhat earlier. However, the use of mathematical and statisctical methods in economics started booming only in the second half of the 20th century. Con-temporary economics is dominated by the mathematical approach, although a certain style of doing economics becomes more and more under attack in the last decade or so. Recent developments in behavioural economics and experimental economics can also be viewed as a reaction against the dominance and limitations of an overly mathematical approach to economics. Similarly There are similar debates in other social sciences.

Wide Variety Of Available Mathematical Methods

Social scientists use a wide variety of mathematical & statistical methods. Given that the space of this paper is restricted, it is impossible to list them all in this paper, examine their domain of applicability, and to discuss some of the philosophical problems they raise. Instead, we broadly distinguish between two different kinds of methods

(i) methods involved in the formal sciences, (ii) methods involved in the natural sciences.

Methods involved in the formal sciences include linear algebra, calculus (including differential equations), the axiomatic method, logic and set theory, probability theory (including Markov chains), linear programming, topology, graph theory, and complexity theory. All these methods have important applications in the social sciences. In recent years, various methods from computer science have been incorporated into social science research as well. There is also a strong trend within computer science to address problems from the social sciences. An example is the recent establishment of the new inter-disciplinary field Computational Social Choice which is dominated by computer scientists

Finally, there are mathematical methods that emerged from problems in the social sciences. These include powerful instruments such as decision theory, utility theory, game theory, measurement theory, social choice theory, and Judgment Aggregation. The latter theories were invented by social scientists, for social scientists and with a specific social-science application in mind. They help addressing specific problems that arise in the context of the social sciences

Why Mathematizing The Social Sciences

A historically important reason for the mathematization of the social sciences was that 'mathematics' is associated with precision and objectivity. These are (arguably) two requirements any science should satisfy, and so the mathematization of the social sciences was considered to be a crucial step that had to be taken to turn the social sciences into real science.

It is a mistake, however, to overestimate the role of the mathematics. At the end, We can say that mathematics provides the social scientist only with tools, and the outcomes that what one obtains when using these tools will crucially depend on the assumptions that are made during the process of solution of the problem. This is a variant of the well known GIGO principle of computer science (“garbage in, garbage out). All assumptions are motivated informally; formulating them in the language of mathematics just helps putting them more precisely. And once the assumptions are formulated mathematically, the methods of mathematics helps to draw inferences in an automated way. This holds for analytical calculations as well as for numerical studies, including computer simulations of various problems.

There are several other reasons for the mathematization in the social sciences. We list them in turn.

Theory Representation: Mathematics is used to formulate a theory. By doing so, the structure of the theory becomes transparent and the relationships that hold between the variables can be determined. Mathematics provides clarity, generality, and rigor. There are many ways to represent a theory. For long, philosophers have championed the syntactic view (basically a representation of the theory in first order logic) or the semantic view in its various forms While these reconstructions may be helpful for coming up with a consistent version of a theory, it apparently suffices for all practical purposes to state a set of equations that constitute the mathematical part of the theory.

Theory Exploration: Once the theory is represented in mathematical terms, the mathematical machinery can be employed to derive qualitative and quantitative consequences of the theory. This helps to better under-stand what the theory is all about and what it entails about the world. The deductive consequences of the theory (and additional assumptions that have to be made) can be divided into retro dictions or predictions. For retro dictions the question arises that which additional assumptions have to be made to obtain a certain (already measured) value of a variable.

Theory Testing: The predictions of a mathematically formulated theory can then be used to test the theory by confronting its consequences with relevant data. At the end, the theory will be confirmed or disconfirmed, or to put in Popperian terms, corroborated or falsified.

Heuristics: Once the structure of a theory is formulated in mathematical term, a look at it may reveal analogies to other phenomena. This may inspire additional investigations (“intuition pump”) and lead to a better understanding of the class of phenomena under investigation. Also, a numerical study of a theory may suggest new patterns that can be incorporated into the assumptions of another theory. A good example of this point is the use of cellular automata for studying the emergence of ordering phenomena, such as in Schelling’s famous Segregation Model.

Explanation and Understanding: While it is controversial what a scientific explanation is, it is clear that – once the theory is formulated mathematically – a phenomenon can be fitting into a larger theoretical pattern (as the unification account demands) or a causal story can be read off from the theory.

Methodological Issues

There are interesting parallels between the use of mathematics in the natural and social sciences. In both kinds of sciences, we find a plurality of methods ranging from axiomatic methods to the use of computer simulations. We also find very different types of models, ranging from toy models (that illuminate one feature of a system in a simple way without scoring high in terms of empirical adequacy) to models that fit a large amount of data (but do not provide much understanding). The mathematization also has similar purposes in both kinds of sciences: it helps to represent a certain object or system, to explain it and to make predictions to test the underlying theory or model. However, there is also an interesting difference. This difference has to do with the relation between the mathematical formalism and the data in the natural and social sciences. Let us assume that we have constructed a mathematical model and we confront it with data. If the data correspond to what the model predicts, the model is confirmed. If the data contradict the model's prediction, then there are two options in the natural sciences: either there was a measurement error, or (or an error can be excluded) the model has a problem. These two possibilities also show up in many social-science contexts. However, there is a third option in the social sciences which has to do with the observation that the data in the social sciences are often not very hard

The softness of the data is probably also one of the reasons why there is much more debate in the social sciences about the usefulness of mathematical methods. The social sciences exhibit a wealth of different approaches, and mathematical methods play a more or less important role in them. The defenders of mathematical methods will argue that mathematics simply provides a host of structures, and as the social world is structured just like the natural world is, some of these structures will fit (or approximately fit). Opponents will either doubt that there are stable structures to be found in the social world, or they will argue that the structures that mathematics (and related sciences) provide do not fit as the social world is very different from the natural world. We take this to be an empirical question and do not see a reason why one should not examine go ahead and employ mathematics in the social sciences.

Besides the general debate about the usefulness of mathematical methods in the social sciences, there is also a lot of debate about the question which methods are most appropriate.

The Development of Statistical Reasoning

Statistical reasoning is nowadays a central method of the social sciences. First, it is indispensable for evaluating experimental data e.g. in behavioural economics or experimental psychology. For instance, psychologists might want to find out whether men act, in a certain situation, differently from women, or whether there are causal relationships between violent video games and aggressive behaviour. Second, the social sciences heavily use statistical models as a modelling tool for analyzing empirical data and predicting future events, especially in econometrics and operational research, but recently, also in the mathematical branches of psychology, sociology, and the like. For example, time series and regression models relate a number of input (potential predictor) variables to output (predicted) variables. Sophisticated model comparison procedures try to elicit the structure of the data-generating process, eliminate some variables from the model, select a "best model" and finally fit the parameter values to the data.

Significance Tests and Statistical Decision Rules

One of the great conceptual inventions of the founding fathers of inferential statistics was the sampling distribution. In the traditional approach (e.g. in classical regression), there was no need for the concept of a sample drawn from a larger population – instead, the modelling process directly linked the observed data to a probabilistic model. In the modern understanding, the actual data are just a sample drawn out of a much larger, hypothetical population about which we want to make an inference. The rationale for this view of data consists in the idea that scientific results need to be replicable. Therefore, we have to make an inference about the comprehensive population (or the data-generating process, for that matter) instead of making an 'in-sample' inference whose validity is restricted to the particular data we observed. This idea of a sampling distribution proved crucial for what is known today as frequentist statistics. That approach strongly relies about this idea of the sampling distribution, outlined in the seminal works of Fisher (1925, 1935, 1956) and Neyman and Pearson (1933, 1967), parting ways with the classical accounts of Bayes, Laplace, Venn and others.

In frequentist statistics, there is a sharp division between approaches that focus on inductive behaviour, such as the Neyman-Pearson school, and those that focus on inductive inference, such as Fisherian statistics.

Conclusion

Let us conclude. In this contribution, we have surveyed and classified a variety of mathematical methods that are used in the social sciences and argued that such techniques, in spite of several methodological objections, can add extra value to social scientific research. Then, we have focused on methodological issues in statistics – the part of mathematics that is most frequently used in the social sciences, in particular in the design and interpretation of experiments. We have represented the emergence of and the rationale behind the ubiquitous significance tests, as well as explained the pitfalls to which many researches fall prey when using them. Finally, after comparing significance testing to rivalling schools of statistical inference, we have discussed recent trends in the methodology of the social sciences and argued that there is reason for optimism, and that awareness of methodological problems, as well as interest for mathematical and statistical techniques is growing.

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