Outliers: The Strength of Minors

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Abstract

Let us think, particularly, about Statistics. Statistics is simply the science of data. It is usually also "applied" because research, most of the times, also implies an application. Statistics is interesting and useful because it provides strategies and instruments to work the data in a way that we can better understand real problems. Data are numbers (or the lack of numbers) inserted in a certain context or experience. To determine the average of 50 numbers is pure algebra, it's not Statistics. To decide over that value of 50 and to choose whether we have a small or a large sample is, in each case, to assume the difference of a certain value (even if we use the average determined before!)—is, in fact, Statistics.

Moreover, let us think, what are the main topics of Statistics for the twenty-first century? What is now "important" comes from the previous century? In one recent ISI congress—International Statistical Institute—(now called ISI WSC—World Statistics Congress) the topic "Water" was elected for a whole day of scientific lectures. Why?

Thinking about investigation, let us bring up the expression "quos fama obscura recondit". [Thinking about investigation. This great expression by Virgil, The Aeneid (Eneid, V, 302) is used, among many other, by Saint Augustine, De civitate dei, (*The City of God*, volume I, Book VII, Chapter III, p. 611 and so on. Education Service. Calouste Gulbenkian Foundation, 1991).] On the one hand, in the dichotomy between the "minor reason" and "a higher reason", should the statistician have, as a goal, (only) the knowledge which allows him to cover all the basic scientific requirements? On the other hand, that knowledge should be the beginning and statistics still assumes the great importance of "scientific

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A. Pacheco et al. (eds.), *New Advances in Statistical Modeling and Applications*, Studies in Theoretical and Applied Statistics, DOI 10.1007/978-3-319-05323-3_2,

details" of those who are hidden by an obscure fame—let's call them *outliers*. They are stimulators of research and they can be originated by different values of the same sample. A minority!

Are these "minors" who make science go forward?! The strength is in them!

1 Statistics as a Science

Science in general and Statistics in particular is a noble occupation, necessary to the body and mind, compulsory to the well-being and to happiness. But the fact is that science is expensive. This way, only the rich can make use of it . . . and the poor become poorer if they employ it. Though great effort and dedication are demanded, the solution (in spite of all this) should probably be in making science to walk out of that dilemma. And this is what it is required to Portuguese statisticians brought together by a leading project—SPE! The Portuguese Statistical Society (SPE in Portuguese) joins both researchers and makers of Science. In the *Memorial* [6], several authors wrote about research. The fact that the chapters are so up-to-date makes that edition an important document in the search and creation of a story on investigation. This topic is crucial for Science and for Statistics.

Statistics affects all and touches life in many situations. As citizens we help to provide statistical information—our own birth and death are recorded to create indexes and rates. Moreover, advertising leads us to believe in something or fools us using statistical facts and figures to support their product.

That's the importance of the individual/of an observation.

Leading a community, through its governmental institutions and trading, depends a lot on the statistical information and that dependence increases even more as the trade influences the economic and social life planning. The advertisers, managers and administrative leaders who use (and sometimes abuse) statistics are a strong number of people. But there are others, considering social science students and politicians. All these people apply statistical facts and methods to build the starting point of politics. Such facts and methods also have a very important place in the development of sociology and economics as sciences. They are also relevant for scientific researchers, considering biology, for instance, and for those who work with the most exact sciences like physics, chemistry or engineering these facts and methods become fundamental.

That's the importance of Statistics.

The statistical ideas are the centre of many theories and, in fact, a "statistical approach" is maybe one of the most distinguishing features of modern science. Finally, statistics as a subject is naturally very interesting for the relatively small group of professional statisticians. As a result of the various ways we found to look at the topic, the word "statistics" and the ones connected to it ("statistical" as an adjective and "statistician" as a noun) have several meanings. First of all, we have the dictionary definitions in which statistics is referred to the topic as a whole and, in a broader meaning, numeric data.

Common sense says that statistics are just numbers. The ordinary user has the tendency to think that a statistician is mainly someone who counts the number of things.

For an economist, used to the economical theory ideas, "statistical" is almost a synonym of "amount". For a physicist, "statistical" is the opposite of the exact, as for him statistics is a subject that above all considers groups and possibilities, more than certainties. For the scientist and investigator who is used to get knowledge from controlled experiments, statistical methods are those which he applies when a rigorous control of an experiment is impossible or very difficult to maintain. The field of application of statistics is mostly economical, but not totally economical—that's why the statistician is often considered an economist. On the other hand, as statistical methods are basically mathematical, many people still think—even today—that the statistician is a sort of mathematician. We could almost assert that the mathematician accepts the statistician as an economist and that the economist considers him a mathematician. Some (few?!) think that statistical methods are so poorly rigorous that anyone can "prove" no matter what; others acknowledge that, because they are such harsh methods, they prove nothing. The third group unites those who state that, as a way to increase knowledge, the power of statistics is unlimited and almost magical.

It is normal to start a book about Statistics, for instance, by defining and illustrating the topic we are referring to. A book in which Statistics is the main topic is obviously not an exception. A (random) reading of the first pages of a book suggests two perspectives for the introductory definitions. These definitions are brief and shallow most of the times. Others interleave identifiable subjects which restrict the text. Let us reflect on the issue overall. Facing the topic of Statistics we can consider many thoughts. The first one is considering that Statistics is at the same time a science and an art. It is a science because its methods are basically systematic and have a general application; it is an art because the success of its application can (also) depend on the experience and the skill of the statistician and his knowledge of the field of application he works in. However, it is not necessary to be a statistician to appreciate the main beliefs that are its basis. As a science, Statistics and particularly the statistical methods are a part of the scientific method in general and is based in the same background and processes.

Thus Statistics, as many other subjects, is always evolving. It is sustained by a theory . . . hence, it is also and above all, progressive! A theory is a set of primary guidelines of a science or of an art with a certain doctrine about them.

Statistics is a science because, basically, it develops a rigorous and rational understanding of a wide range of knowledge in a large sundry of purposes. So, it must be an organised set of information rooted on objective verifiable interactions and with a universal value.

It is obvious, commonly accepted and in a good dictionary we may find a definition for Statistics: it is a science that studies the methodical grouping of social facts which are usable for a numeric evaluation (of the population, of the birth rate and mortality, of the income rate and taxes, of the agricultural crops, of the criminal rate, of the religious beliefs, etc.). In a slender perspective, sometimes

one also elects the word Statistic to refer to a part of applied mathematics which uses probabilities to establish hypothesis based upon real events, in order to predict occurrences. Progress has proved the first is stronger than the latter.

Statistics is the science of data, also applied because research often wants an application. Statistics is interesting and useful because it provides strategies and instruments to work the data in order to best "deal with" real issues. Data are numbers (or the lack of them) inserted in a given context or experience. But to determine the average of 50 numbers is pure arithmetic, not Statistics. To reason over that value of 50, decide whether we have a small or a big sample and in each case to conclude about the disparity of a specific value (even if one uses the average calculated before!) is really Statistics. Though Statistics may be considered a mathematical science, it is not a branch of maths and it shouldn't be taught like one. We can reason about statistical thought which stands and supports the decision theory.

2 Statistical Science: Inference and Decision

Statistics, practically demands judgements. It is easy to list the mathematical hypothesis that justify the use of a certain methodology but it is not so easy to decide about that method, when it can "surely" be used in an empirical point of view. Here, experience becomes crucial. Even in the simplest scientific analysis—and less disputable?—assuming Statistics as a branch of applied mathematics, the final goal is mostly related to predictions. Thus is the pragmatic point of view of Statistics that we are talking about. However, prediction is directly connected to Inference and Decision. Every theory illuminates an empirical point of view and this informs the theory, in a dialectic correlation. Every time we question the users (mainly those who are pragmatically dependent) there are "suggestions" that emerge with "a lot of case studies" and "job offers" with "less theory and more practice". Yet, theoretical support is always acknowledged and it should always be around and available!

We have therefore reached the Theory of Statistical Decision. It is the one where it is founded and where the genesis of the "statistician's job" remains. About this topic—theory—we chose some key ideas by Murteira [4].

"Although man is called to make decisions on a daily basis, only recently have problems with these decisions appeared and were dealt with under a scientific close look." (*ib*, p. 97). Historically, "the theory of statistical decision is essentially due to A. Wald who followed Neyman–Pearson tradition and enhanced the horizons, using the development of the game theory, by von Neumann and Morgenstern. The great worth of Wald (...) is in a contribution for a debate where (...) generally speaking, the standard procedures are peculiar cases of statistical decision" (*ib*, pp. 108–109). Nevertheless, in order to avoid confusions, we should make clear that "(...) the theory that is about to be thought about is connected to the individual decision, not to a group decision. (...) the theory that is about to be analysed isn't trying to substitute the decision-maker—but to bestow a set of rules which

help the decision-maker (...). Generally one might say that this is a problem of decision when it becomes imperative to choose or opt at least between two courses of action" (*ib*, p. 97). But are there others who believe Statistics is not a theory? Could one accept that it is "an instrument or a tool in which its most relevant applications are naturally on the scientific sphere of influence"?[1] "In the scientific assertion problems—or the ones related to statistical decision—one works most of the times with a probabilistic model or, at least with a strong probabilistic component" (*ib*, p. 23).

3 The Need of *Outliers*

All models[2] are very important (they are fundamental!) in scientific research. Besides, in modelling there is (also) the sample and each of its parts—(particularly) its observations and its dimension. Searching for *outliers* in a sample is a research issue that can be fixed... And it will generate (or create the need for support in at least) a Theory! Some scientists assume Theory as a synonym for hypothesis. But theory is different from hypothesis and from science as a global system. As, in the scientific method, the hypothesis is a previous stage of the Theory. And it is an integrant part of science, either theoretical or applied. Theory opposes *praxis* or action, and yet they are complementary. As we know, the scientific method goes through several stages: observation and experiences, hypothesis and drawing conclusions, a general law or a Theory. This is a hypothesis which has been confirmed by experience and is a part of Science. But there are several kinds of Theory and Sciences. Nevertheless, we can only find possible two kinds of Theory: the deductive kind and the inductive kind. As far as the deductive are concerned, there is a series of valid statements or true premises (theorem) which is built upon a group of primitive premises (axioms) by the application of certain rules of inference. In the inductive we find a set of real or probable premises (theorems, axioms and definitions) which is developed according to several particular cases under a process of immediate and generalising inference. To many, the conclusion of induction is only a probability. And the "probability of a law" grows with the number of cases that confirm it. If after careful tests we "confirm a *discordant value*", we have the set or the core of rules that may form—one or the—theory of *outliers*.

One of the most general ways to define Statistics is to consider it a method to choose between alternatives of action facing uncertainty, by collecting and interpreting data about what it is being studied. Thus, in general, the Theory of *Outliers* in Statistical Data becomes a capital gain for Statistical Science. Some worries may follow its construction; yet, obstacles don't seem insurmountable and it is likely that a great future is ahead. The methods of scientific interpretation,

[1] Murteira in [4] quoting Gustavo de Castro, 1952, *Mathematical Statistics as a Scientific Tool*, pp. 52–64.

[2] Brief summary on this topic. For further information read [7].

theoretically speaking, are obviously meticulous and lead us to valid conclusions from a scientific point of view. Besides, the quality of the data used—which affects conclusions—cannot be the support of the accusation of those methods. Bad quality can question methodology. Good data quality is a wishful statistical benefit. And surely quality improves with the Theory of *Outliers*.

In conclusion, (one or the) theory of *outliers* should not only provide a set of rules which helps the decision-maker but also build instruments that can evaluate the quality of the decision. And with that hope . . . we must proceed, although theory should be transmitted in order to grow and to develop itself.

4 Fortune/Chance Decide!?

Considering[3] an analysis of *outliers* in statistical data, let us divide—or split up—the data we are studying into two (two, and only two groups alone?): "the selected", which supposedly has the larger number of observations, the majority, and "the suspicious". The latter (always present?!) has less data points because we ordinarily[4] believe in only one or two *discordant values*. There is no evident reason for that choice. Yet, it is (nearly always) done. The confirmation—of a *discordant/suspected value* as an *outlier*—is (stronger as we proceed) in the use of *outliers significance tests* in most scientific spheres and according to experts on the applications, including statistical packages. Everybody wishes to improve the quality of their work and conclusions through a "purification of the data". Still, can the suspicious hold more, better information than the selected? What is the reason why we choose the selected and not the others? Why aren't the suspicious—which are hidden by an obscure fame—those which are selected in the most eloquent statistical analysis? After all, this is a very important issue: showing[5] which are "the true ones", although we don't get all (the best!) clues out of them, and they allow us to see all the frailties of conclusions. Once we divided the statistical data between the selected and the suspicious, we should question "which is" or "why it is" selected. Who provides that "statistical circumstance"?

Chance[6] is the only thing that doesn't happen randomly. Statistics[7] is very old but it has a very short history. It was considered a subject in schools[8] only in the second

[3]The Roman goddess who, such as the Greek analogous Tyche, operated as she pleased, both happiness and sorrow, according to her wit.

[4]Also for scientific reasons!

[5]It is always the search for Truth that is the issue!

[6]Talking about *outliers*, let us remind this topic. The sentence is from Almada Negreiros (p. 125, *Mathematics and Culture*. Furtado Coelho et al., 1992. Edições Cosmos). This was a topic of discussion in a conference held by Tiago de Oliveira (*ib*, pp. 125–149). Statistics goes well with chance and they both create need. It is a recurring topic which entitled an edition of SPE—Statistics with Chance and Need; Proceedings of the 11th Annual Congress.

[7]About this topic, read the "small expedition" presented by Tiago de Oliveira (*ib*, pp. 125–128).

[8]The articles by Efron and Rao on this matter are important, in [5].

quarter of the twentieth century and its main architect was Fisher—also called the founder of modern statistical science. Certainly Fortune is the leader; she assures us all "the selection" or, on the other hand, "the obscurity", more according to her wit, rather than justice.

But how many are selected and how many are suspicious? If it is Fortune which decides which are the obscure—those which hold "strength"—why doesn't she get that credit for herself? Is it because she suffered a difficult fate herself? In that case, she honours others when she can't honour herself—she is her own opponent! Should the selected always be the majority? And do they deserve more attention? They are often chosen because they are important for the study. Among the selected, which are "the weakest"? Are they all just as good? What is the reason (or the cause) for some selected be considered of minor importance (because they surely exist!)? Moreover, how do we compare "minor selected" and "suspicious"? The latter, already called *outliers*, can detain much more value. It is an *outlier* which allows a deeper statistical analysis. This might be the origin of a work of excellence. It is the choice of a study of *outliers* that can make the difference between a statistician and a user of statistics. This also applies to research. *Outliers*—which are hidden by an obscure fame—bestow data with life. Indeed chance is the one which assures each statistician's fame or obscurity. Let not the one worthy of honour be judged, for he is among the selected. Stronger are those which chance—Mother Nature—has provided with much more (statistical) information. To select them, let us create (at least) a theory! Does Fortune/Chance also decide in research!?

5 *Outliers*: A Path in Research

Experience can turn research into passion. Basic scientific investigation, as well as applied scientific investigation, represents a significant illustration of man over Nature. On the one hand, investigation is *leitmotiv* on the search for Truth. This investigation, on the other hand, stimulates the great(est) thought (ever) that wishes for a reconciliation between reason and faith, which are often questionable. They are like two wings on which the human spirit rises to the contemplation of truth. If scientific investigation follows strict methods and keeps faithful to its own object there is no room for discrepancy. And if the research is based on smaller support—the background ones—it becomes easier to understand the two. They don't actually reach (apparently) contradictory goals.

All great theories start with a small step and, frequently based upon (statistical) data. Because it involves so many subjects, Statistics is shared in Science and for that reason, Research in Statistics is of great importance.

In Statistical Research, such as in many other subjects, one searches for truth. Truth? Search is a permanent course patterned by small steps—unsure and fragile at first—yet firm when experience and wisdom allows it. Notwithstanding, "there are no paths, we have to walk!" (says the poet) because "a path only results in traces . . ." and thus with Statistics.

Let us walk!

As we walk—more this way, less that way—questions about "goals", "interest" or "value" of the "produced science" occur. In the end, there's the "search for truth" and its value . . .

Certainly small contributions are solid because they are easily "controlled", "assimilated" and "ordered". So they occupy their place! Larger contributions, on the other hand, may be more fragile because of the vulnerability of their small support. And the latter, as a whole, create a theory.

Just the same, there are *outliers* in Statistics and many other subjects—from Physics to Metaphysics. There are profound doubts in all of them. Looking at *outliers* wherever they are, we create Science–particularly Statistics. Consequently, we open a (another) path on the search for Truth.

It is the strength of the weakest—the minors!

6 In Perspective

Statistics is also associated with the collecting and use of data in order to support the organisation of a certain state. The justice system is, in fact, one of the fundamental pillars of a modern state and it is basics in the politics of most of the countries. The most recent advance in the theory of *outliers* has emerged from the statistical inference to interpret data in a legal point of view. The legal courts are introducing new challenges for statisticians who are thus asked to speak upon non-traditional lines of work—for instance, the correct application of laws involving authors' rights or, much stronger, the biostatistics or genetic evidences in certain proofs. It is the rise of forensic statistics; probably the most recent topic of *outlier* study.

As we know, the definition of *outlier* depends on the area of statistics that we are working on. According to this, it is not possible to find a "general definition". Time series, for instance, demand a difference between *additive outliers* and *innovation outliers*. Spatial data, on the other hand, ask for a generalisation of the few existing results for circular data, where the influence of its dimension leads us to multivariate data. In multivariate data we are confronted with the additional difficulty of ordering data, which had been crucial for the research of univariate data.

The *outlier* issue can also relate to the general challenge of teaching statistics—from the conceptual point of view and from the pragmatic point of view. This subject is firstly posed when the most part of students' practical education is based on academic exercises. We are much aware that the statistician is also educated by professional practice. Yet, it is important to alert for the actual problems from the experiment's point of view, mainly in the "final education" subjects which involve statistical modelling, for example.

Though with different difficulty levels, many areas of investigation are opened to the study of *outliers* in statistical data. The choice[9] we have made—according

[9]For details: Chapters 2–4, in [7].

to a general approach—has the obvious advantage of turning the field of possible applications vaster. On the other hand, it has limited the study of some primary topics. Among these—has it has been said before—we underline the studies in time series and in surveys or census, where the first developments are very recent. Sure we can say that the general methodology we talked about before is applied here, despite the specificities that come from there.

The existence of an *outlier* is always related to a certain model and an observation can be discordant to a model and not to others.

The great goal in any *outlier* study will always be: *What is an outlier and how to deal with that statement*.

Once we define a theory, as we have said before, it is very important to evaluate the performance of the several tests of discordancy. This is also a sphere where there is much work to do.

The Beckman and Cook [1] study—although it is over 30 years old—made an excellent summary of the statistical approach of *outliers*, either from the historical point of view or from the application of standard models of statistics. Maybe now it is the moment to make a new up-to-date statement. In that study mentioned before, Beckman and Cook ironically conclude that "Although much has been written, the notion of outlier seems as vague today as it was 200 years ago".

What would we say today?

Of course, from then on we have registered an advance, but there is yet much to do.

The development of modern statistical theory has been a three—sided tug war between the Bayesian, frequentist and Fisherian viewpoints. In 1975, Lindley [3] foretold that the twenty-first century would be Bayesian—because 2020 was a crucial year. The Bayesian methods are complicated mainly for the theory of *outliers* where, as we have seen before, there is (always) much subjectivity involved a priori. Is there a great topic of investigation here as well?

Symbolically, as a counteraction, in 1998, Efron [2] predicts that "the old Fisher will have a very good 21st century".

The theory and practice of Statistics span a range of diverse activities, which are motivated and characterised by varying degrees of formal intent. Activity in the context of initial data exploration is typically rather informal; activity relating to concepts and theories of evidence and uncertainty is somewhat more formally structured and activity directed at the mathematical abstraction and rigorous analysis of these structures is intentionally highly formal. The world of applied statistics demands an arrangement between the Bayesian and frequentist ways of thinking and, for now, there is no substitute for the Fisher concept. It is interesting to register ideas about the modified likelihood functions or the pseudo-likelihoods, that is to say, functions of some or of all the data and a part of or all the parameters which can be widely treated as genuine likelihoods.

How do all these questions relate to the statistical study of *outliers*? What is the nature and scope of Bayesian Statistics within the "outlier problem"?

In the study mentioned above, where is this topic in the "statistical triangle"?[10]

This is a scientific challenge for the future. Possibly, this challenge has extra difficulty because we don't know the number of *outliers* in a sample—"outlier problem" or "outliers problem"?

Several topics are in need of more enhancement: the causes (deterministic and statistic) of the presence of *outliers* and the question of their existence in structured models (univariate and multivariate); the differences between simple *outliers* and multiple *outliers*.

On the other hand, different goals we intend to reach when we study *outliers* in a sample influence the conclusions. The outcome of the work done will be varied if we only wish to approach the detection of *outliers* in a set of data, or, if we want to put it together with more complex statistical models, involving for instance the presence of influent observations. Here we will be addressing issues of strength that intersect with the study of *outliers* but which are not the same. According to this, we are not far from the theory of extreme values.

The general theory of *outliers in statistical data*, in several directions, has much advanced in the last 40 years, and in it a great part of the first challenges found the contributions that made it an area of knowledge which already existed as a field of study. Once we reach that phase, we should proceed with wider developments in the (already) explored areas—and the multivariate area will be one of them—as other topics begin to show; and, among them, the most important seems to be performance appraisal. In fact, statistical analysis of multivariate data requires our work in a double way—the tests and models of discordancy. In this topic it is important to produce new ideas because the complex structure of these data is an enemy of the scientific simplicity we need to obtain the greatest success, especially in applications.

In the future, *outliers* will increasingly continue to occupy a place in the centre of statistical science and in statistical methods, because a discordant observation will always be a challenge for the analyst and it can widely influence their final report for the most important decision making. We are talking about excellence!

However, when everything is said and done, the main issue in the study of (supposedly) suspicious observations continues to be the one which defied the first investigators—*What is an outlier and how should one work with that observation?*

In the end of the second millennium, Time magazine organised a list of significant figures of the last thousand years. The names were ordered according to a vote. The first place of "the millennium person" was given to Saint Francis of Assisi, followed by Gutenberg, Christopher Columbus, Michelangelo, Martin Luther, Galileo, Shakespeare, Thomas Jefferson, Mozart and, in tenth place, Einstein.

A winner gathers values that give him distinction. Well, with the goal of electing the person of the millennium, the voters would have ordered their own criteria. The latter, coming from a set of rules, allowed the definition of a first place.

[10] [2] for details.

Thinking about those variables—set of rules or "reasons for the election"—let us bring up the expression "quos fama obscura recondit". On the one hand, in the dichotomy between the "minor reason" and "a higher reason", should the statistician have, as a goal, (only) the knowledge which allows him to cover all the basic scientific requirements? On the other hand, that knowledge should be the beginning and statistics still assumes the great importance of "scientific details" of those who are hidden by an obscure fame—let's call them *outliers*. They are stimulators of research and they can be originated by different values of the same sample—one or more. A minority!

Are these "minors" who make science go forward?! The strength is in them!

Saint Francis is always seen as a reference and a simple life role model. "Francis poverty" is many times mentioned. His name is also connected to "ecology"—and to "peace". *Which would have been, and how can we find out, the most important variables that made Saint Francis the elected one?*

The knowledge of the statistical components that allow to find (and define) a discordant value in a sample is also a topic for the theory of *outliers*. In every model, whatever the criteria of discordancy, to be in first place is to be an *outlier*! Facing the demanding topics on *outliers in statistical data* described above—we quote this "last outlier"—"at least let's start working, because up to now we have done very little".

Acknowledgements Research partially funded by FCT, Portugal, through the project Pest-OE/MAT/UI0006/2011.

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http://www.springer.com/978-3-319-05322-6

New Advances in Statistical Modeling and Applications

Pacheco, A.; Santos, R.; Oliveira, M.d.R.; Paulino, C.D. (Eds.)

2014, XIX, 285 p. 77 illus., 16 illus. in color., Hardcover
ISBN: 978-3-319-05322-6