We are pleased to publish here the speech by Professor Giuseppe Leti, Professor Emeritus of the University of Rome "La Sapienza" and member of the Metron Editorial Committee, given during the ceremony when, upon reaching the age limit, he retired from his teaching career

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The birth of statistics and the origins of the new natural science

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1. HUMAN LIMITATIONS

1.1. Sense organs and their limits

Man's sense organs — sight, hearing, smell, taste and touch, etc., — cannot perceive all the stimuli which they receive.

The eye for example cannot make out an object which is either too close or too far away. Moreover, the most minute details of any object are imperceptible to the naked eye as the retina is physiologically incapable of responding to distinct sensations when two light stimuli are directed at two extremely close points. The retina can only perceive light vibrations between 7.200 Å (extreme red) and 4.000 Å (extreme violet), and never beyond this interval.

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An adult ear can perceive as sound only acoustic vibrations with a frequency of 16-16.000 hertz and, of these, only those with an intensity between the audibility threshold and below the pain threshold.

From contact with other bodies man can receive hot and cold sensations but is unable to measure these. He can also sense humidity in the environment but cannot quantify it.

Animal's faculties are also limited, but different from humans, and tend to vary between species.

1.2. Other human limitations

Other human faculties, not directly linked to the senses, are also limited. Such applies, for example, to man's ability to perform numerical calculations.

Another limitation of the mind regards some phenomena related to human experience. To be able to fully understood these, a distinction must be made between phenomena which require just one observation from those requiring numerous observations. The former are known as single phenomena and the latter as collective or mass phenomena. The need for a collective observation may stem for the fact that the phenomenon in question is composed of a group of individual cases, each of which needs to be observed to understand the collective phenomenon. Such is the case with natality, nuptiality and mortality which may be assessed by counting births, marriages and deaths in a given period and, if necessary, compare these with another collective phenomenon, the number of inhabitants. However, a phenomenon referring to even a single case may be classified as collective if it requires repeated observations. For example, a precise measure of the length of a single segment implies that measurements are taken more than once.

The human mind finds itself in difficulty when having to tackle collective phenomena. Without the aid of particular techniques it is unable to synthetise, as a quantity, the outcomes of a number of observations perceived individually. Thus the human mind cannot "naturally" grasp collective phenomena.

1.3. Overcoming human limitations

Since times remote man has taken steps to use tools to remedy his limited faculties and increase their potential. Sight defects or failings were corrected by the use of lenses, glasses, etc. hearing problems, with the aid of a hearing horn, etc.

Man has also used instruments and techniques to remedy situations not directly linked to the senses. To overcome his ability to perform certain calculations he made recourse to stones ("calculi" in Latin) to help him count. He also devised a means to overcome his mind's inability to quantify collective phenomena: statistics. This is the means that permits a quantitative insight and understanding of collective phenomena, or rather the appropriate technique or method to investigate these.

However, the term statistics also includes the application of this investigative tool to different types of collective phenomena (although given that statistics has a double meaning, to distinguish between them it would be better to use "statistics" or "statistical method" to refer to the technique or method and "applied statistics" to the latter).

2. The birth and development of statistics and the new natural science

As with all branches of science, statistics began as a practical activity, geared towards resolving practical everyday issues. Its exact origins have been lost in the mists of time, although it may be presumed that even the earliest societies needed to know the number of their individuals or families, how many could bear arms, how many heads of cattle, etc. Historical evidence points to this.

It was only at a later stage that statistics was defined as a doctrine, in other words, was held to be a system with the aim of providing rules to perform practical tasks, that is a method. Statistical techniques were first applied to matters of state, demographic questions and social phenomena and thus were largely responsible for shaping the theory and subsequent improvements. Thus, initially statistics was taken to mean both the technique as well as its application to demographic and social questions and State affairs.

Therefore, when tracing the birth and development of statistics its significance at the outset should be kept in mind, incorporating both a method and its application to the collective phenomena described, or in other words, the social sciences.

Statistics, in these terms, was born at a precise time: in the XVII century, at the very same time when, thanks to the efforts of Galileo Galilei (1564-1642) and Isaac Newton (1643-1727) and many other scientists, the new natural sciences and its main branches were also being forged. The same century also witnessed the invention of the calculating machine and the bases were laid of modern mathematics, with the introduction of analytical geometry, mathematical analysis and probability theory.

This coincidence in timing, between the birth of statistics and the formation of the new natural sciences, was not merely accidental. In fact, the new natural science and statistics, as a method and a social science, while belonging to different worlds — natural phenomena , on the one hand, and matters of State and society, on the other, — shared a number of similar or common traits. The process leading to the birth and development of both sciences was based on the same factors and principles and triggered by similar needs. Each could emerge thanks to the XVI century appreciation of manmade tools created in the attempt to overcome man's shortcomings. The new natural science was made possible by the invention and scientific use of instruments which went beyond man's capabilities in their examination of nature. Similarly, statistics as a method, by superseding human inability to quantify collective phenomena, permitted greater insight into these phenomena (originally those concerning the State and society). The new natural sciences and statistics followed the same approach, shared a mathematical basis, and pursued both scientific and practical aims.

3. The origins of the new natural science

3.1. Socio-economic aspects of the scientific revolution

Economic change swept Europe in the XV and XVI centuries, with an all-round increase in production and trade, a new social order and a greater focus on man's life on earth, with a subsequent increase in man's faith in his own abilities and spirit of initiative, to list just some of the effects. Attitudes to the world of nature changed compared with the Middle Ages. Nature was no longer considered as the shadow of an ideal world. This was seen to be a reality, noble in itself, to be explored to its full and thus allow man to intervene in its workings and dominate the underlying forces. Nature in all its aspects was to be studied systematically and freely explored, going beyond the dictates of traditional knowledge. This lay outlook to life in general provided the basis of the ensuing scientific revolution.

Economic growth in the 1600's had a direct impact on the birth of the natural sciences. In response to new needs on the part of society, which continued to enjoy economic expansion, there was a subsequent development of new technologies. Some aimed at improving the quality of life for all (new looms, mills, mining pumps, etc.), others with an entirely different aim altogether (new and more powerful arms), and others which were for purely ornamental purposes (the water display system in XVII century Versailles). To satisfy these new needs technicians had to move on from the practical to a theoretical level, thus raise their own cultural status and frequently call on the aid of scientists. In turn, scientists plied their skills to finding solutions to concrete problems, useful both to the individual and society. Thus the 1600's saw technicians and scientists allies together in a shared task arising from their recognition of the practical usefulness of science, which aimed to extend its validity and thus man's control over nature.

Science's new role and aims were clearly perceived by the more enlightened spirits of the time. Among these, Francis Bacon (1561-1626) clearly predicted that this would ensure not only a general reform of philosophy, but a profound revolution in society itself (Geymonat, 1970, p. 177).

3.2. Knowledge of nature

Man's altered relationship with nature generated a change in how this was studied. One result of 16th century man's functional attitude to nature was the wish to obtain results from studies performed and so scientists had to limit their research to a selected number of phenomena. This new focus on nature kindled an interest in its particular structures and the techniques which allowed man to dominate these and use them to his advantage. This led to the triumph of variety over unity, the breaking down of science into a number of separate disciplines, each claiming its ability to stand on its own two feet and independence of outlook.

Today these divisions are taken for granted — physics, chemistry, astronomy, etc., ultra-specialisation being a major feature of modern society. This concept was totally different from medieval society which envisaged a single organism, where art, philosophy, science and politics were completely intertwined within a system of reciprocal relationships, subordinate to the universal principle of metaphysics and theology (Geymonat, 1970, p. 26).

General theories which had purported to explain the workings of the universe, clearly betrayed their unproductiveness. A knowledge of nature no longer consisted of the elaboration of general theories aimed at grasping the primary principles of reality, from which to deduce a rational explanation for all the phenomenal world. An elaboration where reason prevailed over experience. Nor was this any longer a mere description of a limited sector of experience, where rational explanation played an insignificant role. With the emerging natural sciences a new type of knowledge came to the fore, where the theory and observation of facts were intrinsically linked, to the enormous advantage of both. The results of these new forms of knowledge were still authentic theories, continually and systematically linked to experience, whose logic was guaranteed by a sound mathematical apparatus (Geymonat, 1970, p. 173).

The task of science was not only to "describe", but above all to "explain" these phenomena, or rather construct a mathematical theory, incorporating definitions, axioms and theorems, and from which deduce behavioural phenomena. Mathematics served to quantify nature, identify the quantitative links among phenomena, formulate precise principles of the underlying theories and strictly determine the consequences to be deducted from these principles.

Hence, mathematics, the most abstract of the sciences known to man, became an indispensable tool to interpret and gain insight into the book of nature. The exact opposite occurred during the Middle Ages, where an observer mainly depended on his own sense of perception and inhabited a world where "more or less" reigned and mathematics consisted of a few elementary calculations (at most proportions).

Natural laws revealed by mathematics had to be drawn from experience through the elaboration of data obtained from a survey of nature. If these were not sufficiently accurate the recourse to mathematics would have been useless. Thus the premise to the development of the new natural science was the need for an accurate enquiry into nature, obtaining sufficiently accurate results as to put paid to excessive imprecision.

To achieve this goal what were needed were instruments which would overcome man's limited faculties and increase his powers of observation, thus permitting a more thorough examination of nature.

Equally important was the availability of measurement instruments which were both precise and trustworthy. In fact, any branch of human science can only be considered as a science when it has defined a method of measurement which can functionally define a magnitude and subsequently study the associated phenomena.

A crucial element in pinpointing the laws of nature was the availability of instruments whereby experiments could be repeated again and again under a given set of conditions (Galileo's inclined plane, for example, to study a falling body under variable forces and below gravity).

3.3. New instruments to observe nature

The effective importance of scientific instruments to observe nature came to be fully understood in the 17th century.

Observation tools already exited prior to this century as well as specialised workshops where these were fabricated. The construction of scientific devices — proof of the consideration these were given by the profane — was the widespread fashion in the 1500's, among wealthy families, including that of the reigning sovereign, to collect these stupendous instruments which provided particularly interesting effects.

In the 1600's these devices were no longer seen as a collector's item, highly decorated and embellished objects having gone out of fashion, and appreciated more for the new observations and mind expanding operations which they made possible. The appearance of radically new instruments introduced a qualitatively different dimension to traditional scientific equipment and helped shape the new science. The need to scientists to improve their powers of observation provided the impetus to invent new instruments, in turn encouraging them to go on increasing the number of observations carried out.

The 17th century scientist often had to perfect the craftsman's art and indeed become something of a craftsman himself if he wished to construct new instruments or improve on those already in existence. However, at times, too, the craftsman turned inventor and used these new tools with such skill that he stumbled across a number of major discoveries, his means of imposing himself on the world of culture. It would appear that the scientist's guild was open to all, scientists and non-scientists alike, that is to anyone who actively contributed to the new science.

Optical instruments

One example of a scientist who made his own instruments was Galileo Galilei. He was not the inventor of the spyglass that by the early 17th century was already known in France and the Netherlands, where an example had already arrived from Italy by 1590. However, he was the first to recognise its full scientific potential. He himself perfected the telescope, increasing its magnifying powers more than that of any other spyglass of the time. In his home laboratory Galileo produced several examples of his telescope, both for his own personal use, as a present to bestow on others or to sell (at considerable profit) to princes, cardinals, important members of society and scientists from far and wide. Using his telescope, Galileo made a series of important discoveries including Jupiter's satellites, the different phases of Venus, as well as various observations of the sun and the moon, undertaking, for the first time, a systematic study of the solar spots. Galileo also adjusted the telescope to be able to see objects close up and thus discover "minutiae" invisible to the naked eye, during which he made numerous interesting observations of flies.

An example of a major scientist, although not so by profession, is Antoni van Leeuwenhoek (1632-1723), a Dutch cloth dealer. Among the many microscopes built during the 1600's, particularly sought out were the minute microscopes built by van Leeuwenhoek after 1673, about 500 samples in all. He performed a number of amazing observations, revealing a world that was finely structured and invisible until then. He discovered red blood cells, spermatozoa, capillaries, bacteria, rotiferi and the structure of the crystalline lens. Van Leewenhoek also sought to provide measurements of the objects he observed, as fractions compared with a sample (a strand of hair, a grain of sand). The instruments he created and his ensuing discoveries procured him such far-reaching fame that eminent people from all over the world, including Peter the Great of Russia, came to visit him.

Measuring tools

The inventing and perfecting of new measuring tools throughout the 17th century provided fresh impetus to progress in the natural sciences.

Most of these were created, perfected or adapted to the needs of science by Galileo and his disciples including Benedetto Castelli (1577-1644), Bonaventura Cavalieri (1598-1647), Evangelista Torricelli (1608-1647), Giovanni Alfonso Borrelli (1608-1679) and Vincenzo Viviani (1622-1703).

Galileo's followers performed their experiments at the Academy of Cimento which was founded in 1657 in Florence, with the support of the Grand-duke of Tuscany. The Academy by *provando e riprovando* made a key contribution to the study of nature, basing its work on the collaboration of its single members and systematic collective enquiry, the forerunner of today's work-group. A review of the first ten years' work of the Academy was published in 1667 under the title, *Saggi di naturali esperienze fatte nell'Accademia del Cimento*. This offered a description of the various experiments they performed, with no reference to the names of the individuals concerned. The work of the Academy was widely acclaimed by the scientific community of the day. Sadly, however, the publication also marked the swan song of their activity. Despite its international fame its activities, as mentioned later, were suppressed exactly ten years after its foundation.

Measuring tools which were much improved on during the 17th century included mechanical clockwork measures. Their earliest known construction dates back to the Middle Ages, with portable clocks appearing for the first time in the 15th century. These were by no means precise until Galileo's discovery of the isochronism of the small swings of the pendulum and its application to clockwork mechanics. Based on his studies of the cycloid, Christian Huygens (1629-1695) further expanded the theory of the isochronism which he then successfully applied to the construction of clocks.

It would appear that Galileo was also the first to construct an elementary form of the thermometer. This thermoscope, which was water based, was then perfected at the Academy of Cimento, where water was replaced by "acquarzente", pure alcohol in other words, and then sealed airtight. These became widely available in the latter half of the 1600's and were known as "Florentine thermometers" throughout Europe. Sometimes they were graded, but the scale was totally subjective and usually left up to the glassmaker who made them. To obtain real temperature gauges, in other words, thermometers, we had to wait for the discovery of the constancy of the temperature at which water boils by the French physicist Guillaume Amontons (1663-1705). Using this law and the constancy of the temperature at which water solidifies, thermometric scales were introduced during the century: that by the Dutchman Gabriel Daniel Fahrenheit (1686-1736) (who replaced alcohol with mercury), by the French René Antoine Ferchault de Rèamur (1683-1757) and the Swede Anders Celsius (1701-1744). With the introduction of precisely graded thermometers it was possible to accurately quantify thermal phenomena and underpin the first laws of thermology.

The invention of the barometer was the outcome of the famous experiment by Evangelista Torricelli who used "quicksilver", i.e., mercury. The first to exploit this discovery as a barometer was René Descartes (1596-1650). After him numerous scientists tested out other versions of the barometer among whom the French Amontons and Blaise Pascal (1623-1662) who performed a number of fundamental studies with fluids, the English physicist Robert Boyle (1627-1691) who coined the word "barometer" and formulated the famous law of gasses, and Robert Hooke (1635-1702) who invented various other scientific devices. Torricelli's experiment was widely acclaimed by scientists and was particularly crucial in that it led to the discovery of atmospheric pressure, and its dependence on altitude and the link between variations in pressure and changes in weather. He also sparked off a lively discussion on what is a vacuum, involving many scientists of the day.

In 1639, Benedetto Castelli, a disciple of Galileo, projected a pluviometer. Santorio Santorio di Capo d'Istria (1561-1636) built an anemometer, and a hygrometer, using a rope. This was later perfected by Vincenzo Viviani, a pupil of Galileo, by replacing the rope with a strip of paper which is more sensitive to changes in humidity.

3.4. Conceptual tools

Scientists of the day made recourse to mathematics to quantify reality. Indeed, enormous advances were made in mathematics throughout the 17^{th} century, in part provoked by the queries raised by the new nature science and partly under its own steam.

The three mainstays of modern mathematics were laid down during this century: analytical geometry, by Descartes and Pierre Fermat (1601-1665), completely irrespective of each other; infinitesimal analysis, founded by Isaac Newton and Gottfried Wilhelm Leibniz (1646-1716) and the probability theory, devised by Pascal and Fermat. Lesser discoveries, but only in the sense that they were outshone by those just mentioned, included projective geometry, conceived by Gerard Desargues (1646-1716), which the young Pascal also made a major contribution to; logarithms, devised by John Nepero (1550-1617), the theory of which was further elaborated by Henry Briggs (1561-1630).

New branches of mathematics which were developed during the century, not to mention those already existing and improved on in that period, provided the conceptual tools required by the new natural sciences. (Probability was not called into play until two centuries later when it became obvious that many natural phenomena were collective and warranted investigation using statistics).

3.5. Calculating machines

A 17th century invention which has only recently been given due credit was the calculating machine invented by Pascal. Barely 19 in 1642, he devised an arithmetic device to assist his father who was in charge of apportioning taxes in Normandy. The device, known as the "Pascaline" could automatically carry over as well as do addition and subtraction. A final version was devised in 1645. Taking Pascal's design, an Englishman, Samuel Morland (1625-1695) constructed various exemplares of a machine which could also do multiplication. The famous mathematician Leibniz also constructed a machine which could multiply.

4. The origins of statistics

4.1. Background formation

Statistics originated in the amalgamation of three currents of thought, each emerging in a different European country in the second half of the 1600's: the German descriptive statistics, the British Political arithmetic and the French support for statistical surveys and thus their aim to determine their methodology.

An indispensable tool for the new emerging science was provided by the probability theory, whose origins are undoubtedly French.

It is worth taking a look at the individual role played by each branch in developing statistics as we know it today.

4.2. Descriptive statistics

Increasing specialisation and fragmentation of post-medieval culture, referred to above, was also a feature of the branch of investigation, later to be known as descriptive statistics. Herman Conring (1606-1681) a professor of Public Law at the German University of Helmstedt, a vastly learned man, introduced a course in political science in 1660. Although he did not employ quantitative data, he investigated and described important matters related to a State. He enjoyed an immediate success and his course was used as a model by academics in other German universities. Somewhat later the Hungarian academic, Martin Schmeitzel (1679-1747), taught at Jena, entitling his course *Collegium politico-statisticum*. One of his students was Gottfried Achenwall (1719-1772) who, on being nominated to the teaching staff of the University of Gottingen, called "statistics" his branch of teaching. The guiding principle of his course was to describe matters of importance to the State (at times the word "descriptive" was added to the name "statistics" so as to underline this particular feature). Achenwall enjoyed such acclaim that he overshadowed Conring's pioneering efforts and the branch of teaching Conring had introduced came to be known as "Achenwallian statistics". It should be pointed out that Achenwall added nothing new to Conring's efforts. His real success lies with the fact that he emphasised the autonomy the descriptive statistics from other areas of knowledge, helped increase its popularity among contemporary academics and showed how this branch of learning could be usefully applied to running public affairs.

Numerous university chairs in statistics sprang up in Germany, so much so that this new branch was then termed "university statistics".

A powerful, authoritative voice, favouring this new area of investigation, was provided by Leibniz. He proposed the setting up of an academic body which, to the advantage of the Government, would perform functions which today are those of a Central Statistics' Bureau.

University statistics was still relatively new when it passed through a crisis which other areas had already taken on board sometime previously, i.e., the passage from a qualitative to a quantitative description of matters of importance to the State. In 1741, in Denmark, a book by J.P. Anchersen , titled *Descriptio statuum cultiorum in tabulis* was published, systematically using for the first time statistical tables. This approach was firmly opposed by university statisticians. They feared that these skeletal tables would negate the usefulness of the learned dissertations they held in their universities, and thus fought tooth and nail to defend "statistics" from the "slaves" of tabulation. However, as the latter soon acquired an increasing quantity of data, they eventually won over the adversary. Thus description became quantitative, the content beginning to resemble the content currently comprising statistics.

Quantification necessitated data collection and an exposition of the data gathered and, thus, tables and figures. This new branch of investigation had a name, "statistics", (and far too many adjectives:

descriptive, Achenwallian, university) and a series of technical procedures. Its scope at this stage was purely descriptive, the search for underlying laws being as yet unknown. Therefore statistics could not yet be considered as a science. Any branch of investigation which limits itself to collecting and describing facts and data, irrespective of how interesting they may be, may not be said to have attained scientific status. It is through the search for laws that this status is attained (Gini, 1954-55, p. 9).

4.3. Political arithmetic

In England, at the same time, another current developed displaying all the features of an investigative science.

The first in a long series of scholars who contributed to the creation of this new current of thought in England were two friends, John Graunt (1620-1674) and William Petty (1623-1687).

John Graunt, a talented merchant, used parish registers (baptisms, burials, etc.), until then referred to by his colleagues for more practical ends, to make certain scientific inferences. He brought to light for the first time the excess of male births over female (104-5 males births for every 100 female), and studied the urbanisation of the population, and the link between suicide and social aspects of suicide. He also calculated the population of London, until then much overestimated and constructed a life table, making a number of courageous conjectures, as age at death was not recorded. In 1662, in his *Natural and Political Observations upon the Bills of Mortality*, Graunt urged the study of demographic and social phenomena based on numerical data, and thus the use of mathematics. Therefore, in the social sciences as elsewhere, mathematics served to quantify reality and identify quantitative links among social phenomena, or rather the underpinning laws. These, however, had to be obtained from experience by processing data from surveys of society. As with natural phenomena, a study of social phenomena entailed the application of an inductive empirical method. Thanks to the efforts of Graunt in the social sciences, the science of the population (Gini, 1954-55, p.9) was first forged.

Graunt's pioneering work, at a time when it was widely believed that there were three women to every man, and that every change of government was followed by an outbreak of plague, marked a major step forward for social science, despite the approximate nature of the results obtained.

Some scholars doubted that a simple merchant, such as Graunt, could possibly have made such an enormous contribution to the birth of this new current of thought. It has been suggested that he was merely a cover for Petty's earlier work, who along with Graunt, is considered the father of the new social science. This is considered untenable by investigators who nourish no doubts regarding the contribution made by another cloth dealer, namely the Dutch Leeuwenhoek.

Petty, who was more of a theorist than Graunt, was highly educated with a vast range of interests spanning medicine, the natural sciences, anatomy, and pedagogy. Petty, together with his theoretical studies, like Graunt, performed empirical research based on a quantitative, and not only a qualitative, assessment of the phenomena at hand. He estimated the population of London (about 700.000), Wales, Ireland and the colonies. He pinpointed the total mortality due to the plague as well as making forecasts regarding population trends. His studies also went beyond purely demographic matters as his interests also lay with economic issues. He felt it was necessary to have a detailed knowledge of agricultural output, industrial production, as well as imports and exports. Petty distinguished himself from other contemporary observers of the economy in maintaining that economic questions — monetary, international trade, or whatever — should be seen as part of a whole and not separately. This need he expressed for a "system" places him a step ahead of his contemporaries and has led to him being labelled as the "founder of modern political economy" (Roncaglia, 1977, p. 39).

It was Petty who coined the name "Political Arithmetic" for the emerging current of thought. He explained the reasons for his choice in a letter to Southwell on 3 November 1687: "W[illiam] P[etty] hath applyed it [algebra] to other then purely mathematicall matters, viz: to policy by the name of *Politicall Arithmitick*, by reducing many termes of matter to termes of number, weight and measure, in order to be handled Mathematically" (Petty, p. 15). He held that the questions of State follow the laws of algebra and that social reality had a mathematical structure. To best describe and interpret this, mathematical procedures had to be applied, ensuring that social phenomena were treated with precision.

Political arithmetic was also defined as the art of reasoning by means of figures matters pertaining to the government. This definition throws light on the difference with descriptive statistics. Although the field of study, the aims (the public interest) and the means (numbers) were similar, the method was quite different (interpret rather than merely describe the data obtained).

Other well-known workers in the field of Political arithmetic included Charles Davenant (1656-1714) and Gregory King (1668-1712) who studied economic, financial and actuarial issues besides demographic questions. The astronomer Edmund Halley (1656-1742) (known for the discovery of the comet named after him) may also be included in their number. He devised a method to calculate life tables, which he then applied to the list of the dead for the city of Breslavia (sent by Leibniz to the Royal Society and entrusted to Halley).

Thus nestling in the cradle of Political arithmetic we find the twin sisters demographic statistics and economic statistics, modern political economy and actuarial sciences.

4.4. The French contribution: methodology of statistical surveys and the probability theory

The methodology of statistical surveys

The French School's contribution to statistics by their use of the census is on the same scale as that made to the natural sciences by the inventors of new instruments to study nature.

In 1637, Descartes in his *Discours de la méthode* emphasised the need for complete, general enquiries so as to ensure that nothing was overlooked.

However, it was Sébastien Le Prestre, Marquis of Vauban (1633-1707), who advocated the introduction of official statistics and underlined the need for censuses. Not limiting himself to a series of proposals and recommendations, in 1686, in his *Méthode générelle et facille pour faire le denombrement des peuples*, he laid down the rules for performing censuses and which are still valid for us today. It was Vauban who saw that the census should be applied to everybody, regardless of status (for instance, children were excluded at that time), distinguishing by sex, age and marital status. He also suggested that printed forms for each family should be given to the interviewers and invented a special code to quickly observe the data to be collected. He also encouraged other types of surveys to cover land ownership, forests, cattle and mills. In 1696 he personally oversaw a census that applied the norms and proposals he had made.

Vauban demonstrated just how necessary and feasible censuses were. He also underlined their enormous potential as a means of knowing reality and their importance in ensuring a more efficient and just administration of State affairs. Thanks to him censuses soon became common practice in France, then spreading to many other European countries.

Vauban shone too in other fields. He was a famous military engineer and strategist. He renewed the system of defence using ramparts and bastions and built or modernised more than 300 forts (including Saint-Malo, Verdun, etc.). He constructed canals, aqueducts, churches and drew up urban plans. Louis XIV expressed his appreciation for Vauban's many efforts and appointed him general commissioner for fortifications and subsequently director of wartime sieges and Marshall of France. Vauban, however, could not but fall out of favour when, in the name of a fairer administration, he supported the need for fiscal reform which was aimed at the rich and exempted the poor from paying taxes.

Vauban's contribution to statistics is still valid today. Ironically, however, he is best remembered for his efforts in the military field, then precursors, but today hopelessly outdated.

Probability theory

A crucial element in studying social trends is, as pointed out previously, probability theory. This had its origins in France in the second half of the 17th century and developed as a separate branch of mathematics, mainly due to the efforts of Pascal and Fermat. In an exchange of letters between the two in 1654 they resolved a number of questions regarding games of chance proposed by Chevalier de Méré. Three years later Huygens highlighted the notion of mathematical expectation, which Pascal and Fermat has referred to. However, the main theorem, the law of large numbers, was the work of Giacomo Bernoulli (1654-1705). He was Swiss, of French origin, and was the author of *Ars conjectandi*, the first important treatise on the probability theory. He captured the novelty and full potential contained in this theory, essential in statistics, in all its many applications, in the economy and all other experimental sciences.

4.5. The different branches merge

During the 1600's the term statistics passed from Germany to England, and continued to indicate Achenwallian descriptive statistics. However, as England was the home of Political arithmetic not even the most faithful followers of Achenwall could content themselves with a mere description of the facts. There was a constant need to compare these with other facts, which were considered as either the cause or the consequence of the former. It followed that university statistics were increasingly imbibed with the spirit and methods of Political aritmethic. Gradually the two approaches began to merge, sanctioned by the Scots John Sinclair (1754-1835). Instead of Political aritmethic, from 1790 he began to refer to the term “statistics”, the word used by the German school used to descriptive statistics: “as I thought that a new word, might attract more public attention, I resolved on adopting it and I hope it is now [1798] completely naturalised and incorporated into our language” (Sinclair, 1798, p. XIII). We should note K. Pearson’s ironic comment (1978, p. 2): “A Scotsman steals the words “Statistics” and “Statistik” and applies them to the data and methods of “Political arithmetic”. Thus the term “statistics” is the outcome of the merger between German descriptive statistics and the English Political arithmetic.

The main thrust favouring the fusion between the different founding spirits of statistics was that one single method was recognised for the study of collective phenomena, i.e., the statistical method, which was lent further support by the contribution from the French School.

5. Features of the new natural sciences and statistics and similarities in their birth and development

In tracing the birth and development of the new natural sciences and statistics we have come across a number of major scientists who were involved in both: Huygens, Descartes, Leibniz, etc. This is proof of the fact that both disciplines were children of the same intellectual environment. It was then common for observers who also dealt with different disciplines to transfer their methodological knowledge from one field to the other and, if possible, also any results matured.

The field of study of both the natural sciences and statistics was quite different: natural phenomena for the former and collective phenomena in society and the State for the latter. Nonetheless, as outlined in paragraph 2, in their birth and development they shared a number of similar features.

1) They each sprang from the same intellectual background, which welcomed contributions from observers also operating in different fields and who were not necessarily professional scientists;

2) They were spurred by a new vision of the world (with regard to nature and society, respectively), which differed from that of the previous epoch, no longer viewed as a shadow of an ideal world but as a reality which had to be fully explored in total freedom and allow man to draw every possible advantage;
3) They were conceived of for practical purposes (the aim of natural science was to dominate nature for the benefit of mankind; that of statistics good government and the public interest) and thus adopted a functional approach to reality;
4) Their goal was to provide a quantitative description, offer an explanation for the phenomena being studied and pinpoint the underlying laws;
5) The inductive empirical method used was based on:
   a) observing the facts
   b) the use of mathematics, on the basis of the facts observed, or rather experience, to elaborate the laws governing these phenomena (conceptual tools for the natural sciences were analytical geometry and infinitesimal analysis and, not until two centuries later, the probability theory, used from the very outset in statistics)
6) The collected quantitative data had to be exact to enable the application of mathematical procedures and thus the need for valid tools of observation;
7) They were made possible by the construction of new instruments that helped overcome man's shortcomings and thus enhanced his powers of observation. The birth of the natural sciences went hand in hand with the discovery of new tools compensating for mankind's limited senses (telescope, microscope, clocks, thermometers, hygrometers, etc.). Statistics originated with the devising of statistical the technique which made up for the mind's inability to quantify collective phenomena (censuses, statistical surveys, etc. and the use of modules and questionnaires to collect data and tables and figures to represent these);
8) They gave rise to various disciplines. Offshoots of the new natural sciences included physics, in all its branches (mechanics, acoustics, optics, etc.), astronomy, chemistry, biology, etc. Statistics gave shape to statistics as we know it today, demography, social statistics, economic statistics, actuarial sciences, political economy, biometrics, anthropometrics, etc.

Table 1 provides a description of the main features of both the new natural sciences and statistics, as well as outlining similarities in their birth and development.

TABLE 1: *Features of the new nature science and statistics and similarities in their development process.*

	NATURAL SCIENCE	STATISTICS
Focus of knowledge	Natural phenomena	Collective phenomena regarding the State and society
What generated the process of development	A new focus on naturalphenomena and a functionalapproach to nature	A new focus on political and social phenomena and a functional approach to State and society
New scientific method	Inductive empirical method based on experimentation (try and try again),where the quantitative observationof facts and their theoretical elaboration are inseparably linked	Inductive empirical method based on the quantitative observation of collective phenomena concerning the State and society and aimed at deducing the laws involved (elaborated using descriptive statistics and Political arithmetic and completed using the methodology of statistical surveys)
Method of observation	Collect quantitative data obtained using exact measures of natural phenomena	Collect exact quantitative data on collective phenomena regarding the State and society
Tools of observation aimed at overcoming man's limitations and enhancing his abilities	New tools of enquiry and measurement capable of compensating for man's limited sensorial faculties and enhance his powers of observation (spyglasses, telescopes, microscopes, clocks, thermometers, etc.)	Statistical technique to compensate for the mind's inability to quantitatively perceive collective phenomena (censuses, statistical surveys, etc. using models and questionnaires to collect data and tables and figures to present these)
Tools of elaboration and study	Mathematics, and particularly: analytical geometry and infinitesimal analysis	Mathematics, and particularly: probability theory
Scientific goals	Describe in quantitative terms natural phenomena and explain these and identify the law involved	Describe collective phenomena concerning the State and society and explain these and identify the laws involved
Practical goals	Dominate nature for man's benefit	Good government and the public interest through a knowledge of the State and society
Autonomous derived disciplines	Physics (mechanics, optics, acoustics, etc.), astronomy, chemistry etc.	Statistics, demography, social statistis, economic statistics, actuarial sciences, political economy, biometrics, anthropometrics etc.
Scientific environment	Open to non professional scientists	In process and almost completely open to non professionals

6. ITALIANS FAIL TO CONTRIBUTE TO THE BIRTH AND DEVELOPMENT OF STATISTICS

At this stage some attempt must be made to answer the question: "*Why, during the 1600's, did Italians fail to make any contribution to the birth and development of statistics, despite the fact that many of them were precursors in the field and that Italians had made a crucial contribution to the new natural sciences?*"

As we saw Italy in the 1600's was leader in the field of the natural sciences. Pre-eminent figures were Galileo and his disciples, who could boast an array of discoveries and observations. It may be stated that the first scholars in mechanics, optics, astronomy, geography, medicine and botany were all Italians.

Among precursors in the methodology of statistical surveys we find Francesco Guicciardini (1483-1540) who exhorted European sovereigns to follow the example made by the Romans and perform population censuses. Nor should we overlook the fact that the Papal States were the first to use a printed questionnaire for a statistical population survey in 1656, in Perugia (Leti-Tittarelli, 1976, p. 88).

A forerunner in descriptive statistics was the Venetian Marin Sanudo (1466-1535) who, in his book titled the *Vite dei Dogi* (Lives of the Doges), wrote a commentary on Venice. In places he veers away from his account of local history and describes local customs and uses, trade and the public economy. Still in Venice, Francesco Sansovino (1521-1586) published in 1562, *Del governo et amministrazione dei diversi regni et republiche cosÏ antiche come moderne* (On the government and administration of various kingdoms and republics, both modern and classical). This provided a description of some 22 states, including one called "Utopia" (!). Another famous precursor of descriptive statistics was Giovanni Botero (1544-1617), a diplomat who journeyed widely throughout Europe. He published his *Le relazioni universali* in 1591-1611 that offered a political-geographical description of the world States, focusing on economic and social aspects.

Italian forerunners in the field of Political arithmetic included Santorio Santorio di Capo d'Istria — some of whose inventions have already been mentioned. He pinpointed a quantitative method to study man and related basal metabolism to age, temperature and environment.

Gerolamo Cardano (1501-1576) was also ahead of his time in constructing the first life table in 1570, despite the meagre data available. He also did some early work on the probability theory, although even earlier attempts were made by Luca Pacioli (1445-1514) and Nicolò Tartaglia (1499-1557). Galileo anticipated statistical methods when, applying an objective familiar to statistician's today, by a sort of fitting, he attempted to separate the systematic component of the error, and Boscovich-Laplace's method of last absolute values (Hald, 1990, p. 160). Galileo also proposed a number of hypotheses that generated the distribution of observational errors (Hald, 1990, ch. X and Forcina, 1996).

Thus the question put previously could be reformulated as follows: "*Why did the efforts of these Italian scholars not naturally conclude in the construction of a system as was the case with France, Germany and England?*".

One reason may be Italy's reduced economic competition on international markets. The discovery of America undermined Italy's role in foreign trade, which now shifted its focus to the North Sea and Atlantic European routes dominated by the Dutch and English by the Netherlands and England. This saw a steep decline in Italy's maritime and trade activities, banking and manufacture, where Italy had had a prime role. Thus, economic activities, favouring the accumulation of capital, were no longer in Italian hands.

By the sheer force of inertia a number of industries continued to thrive throughout the 17th century, but no later, such as the production of silk, luxury clothes, ceramics, metals and quality woods, glass and precision tools (lenses, glasses, and other optical equipment). However, by the end of the century the decline had set in and France had replaced Italy in the production of high quality artistic goods.

The 17th century saw an exodus of capital, initiative and persons from Italy: artists, "condottieri", men of letters, adventurers, etc. all left the country. This was a terrible drain on Italy. What capital remained tended to concentrate in land ownership, completely ignoring other sectors, and creating colossal land holdings in the hands of the Church and the privileged classes. Italian society subsequently underwent a process of "ruralisation", where the bourgeoisie were very much weakened, while the nobility and the Church powers consolidated their power and privileges. Social renewal almost ground to a halt.

The plagues of 1630-31 and 1656 further contributed to this trend.

However, economic decline in Italy did not curtail developments in the natural sciences. The same may not be said for technological progress and the birth and development of the social sciences.

Another factor preventing the birth and development of statistics in

Italy was the break down of the country into a number of smaller states which, owing to their size and late origins, were much more unstable than the ruling monarchies found in England, France, etc. Nonetheless, these factors only offer a partial explanation in that Germany, which made a major contribution to the birth and development of statistics, was also divided into a number of smaller states, and a united, stable country like Spain made no contribution at all.

A comparison between the Italian principalities partly occupied by Spain, and Spain itself would pinpoint the main reason for this failure to contribute to the creation of statistics. And the reason could lie with that fact that both countries were very caught up in the Counter-reformation. Italy lost both her political independence and intellectual liberty because of the Inquisition and the Spanish occupation.

The 1600's marked a period of submission by Italy to the ruling powers, be they State or religious, as well as a passive acquiescence to authority, tradition and conformism. The great names of the century, those which have gone down in the page of history, are the names of rebels. They refused to flow with the tide, rowing against it and thus paying a heavy price for their stance against the ruling powers and for having questioned the official doctrine of the church in areas which had little to do with the word as revealed by God. The renowned Flemish anatomist, Andrea Vesalio (1514-1564), teacher at the University of Padua, was condemned to death. Because of his fame his sentence was commuted to a pilgrimage to the Holy Land, from which however he failed to return (Gini, 1958). Gerolamo Cardano was accused of heresy when he was about 70 years old, imprisoned and briefly detained. He also lost his chair at the University of Bologna, and had to commit himself not to hold public lessons in any of the Papal States nor publish his writings (Gini, 1958). The early 1600's were illuminated by the flames of Giordano Bruno burning at the stake in Rome (1548-1600). Another nature philosopher, Tommaso Campanella (1568-1639), languished in a ghastly prison for over 27 years and then fled abroad. Even Galileo, the father of modern science, was persecuted for his position in favour of the complete autonomy (not oppostion) of science from any doctrinal authority. Thanks to his fame among other academics he was not subjected to physical torture nor the gallows. He was forced, however, to renege Copernicus's theory, declared incompatible with the Catholic faith and confess, "*Terra stat et in aeternum stabit*", even though his conscience told him that, "*Eppur si muove*" A number of his writings were placed on the banned list

(Index librorum prohibitorum), which also was to include publications by Copernicus, Kepler and Descartes (Hald, 1990, p.24). Galileo's *Dialogo dei due massimi sistemi del mondo* was later declared "more abominable and pernicious for the Church than the writings of Luther and Calvin". Galileo was then condemned to life imprisonment, commuted to "house arrest" and cut off from the rest of the world (he carried out his sentence in Siena and then at his home in Arcetri). Thus Galileo emerged defeated from his battle. Even his School was reduced to silence although here the church powers used kid gloves. As stated above the Academy of Cimento was closed down after only ten year's activity. Its president, however, Prince Leopold, was appointed cardinal by the Roman Curia, probably by way of compensation.

The ecclesiastical authorities allowed certain studies in the natural sciences to continue as long as these did not clash with church doctrine. Other areas were totally out of bounds for the scientist wishing to throw of the shackles of tradition in the unprejudiced search for the truth.

In Italy this climate sufficed to stifle any impulse to adventure into the scientific investigation of human society, a task fraught with danger. The same obstacles limited progress in literature and philosophy, reduced to mere erudition, an area unbeset by the perils of science. The 1600's can thus be seen to a century of decadence and stasis in the humanities in Italy. This was not the case in other countries as the State powers, having consolidated their political unity, managed to keep the counter-reformers at bay.

Although Italians were denied the possibility of contributing to the development of statistics nonetheless something Italian does remain: the name. In 1589 Gerolamo Ghilini used the word "statistics" as an adjective in the title of his book, "*Ristretto della civile, politica, statistica e militare scienza*". In 1749 Achenwall, in his book "*Abriss der Staatwissennschaft europaischen Reiche*", associated the Latin denomination "statistica scientia" with the German noun "Statistic". In 1768 he proposed using this to describe his teaching course at the University of Gottingen. A note was found in the University library where Achenwall had written, "Statistics does not come from the German word Staat but, is a word that is not new. It was already in use in the XVII century and has its origins in the famous Italian "ragion di stato". The Italians, from "ragion di stato" coined the word "*Statista, i.e. Man of the state, Staatsmann*". German languange writers adopted this term, and thus the name of this branch of learning ... It is mistaken to write Staatistica".

7. Conclusions

The birth of the new sciences coincided with the scientific appreciation by mankind of the tools made by man to compensate for his limited faculties. By overcoming his limited senses this paved the way for the birth of the new natural sciences and, by overcoming problems of quantifying collective phenomena, generated the birth of the statistical method and the social sciences.

The scientific revolution swept away classical as well as medieval science and signalled the origins of modern science and the contemporary world. The new natural sciences and social sciences radically overhauled man's usual mental operations and the very structure of his existence and thus, as predicted by Bacon, were the moving forces of a deep rooted revolution in society.

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The birth of statistics and the origins of the new natural science

SUMMARY

Statistics as a method to provide a quantitative knowledge of collective phenomena and as a social science was born from the fusion of three main currents of thought. These emerged in three different European countries during the 17th century: descriptive statistics in Germany, political arithmetic in England, and in France, where the usefulness of statistical surveys was promoted, and thus their aim to determine their methodology. Seventeenth century France was also responsible for devising the probability theory, which soon proved to be an indispensable mathematical tool in the field of statistics. Throughout the same century, thanks to the efforts of Galileo Galilei, Isaac Newton and various other scientists the new natural science was being forged. The calculating machine was invented and the foundations of modern mathematics were laid with the introduction of analytical geometry and infinitesimal analysis and probability theory.

Although the new natural science and statistics were related to two different worlds — natural phenomena on the one hand, and matters of State and society on the other — they nonetheless shared several common or at any rate similar features.

The processes leading to the birth and development of these two sciences involved the same set of factors and principles and were stirred by the same needs and demands. Each could emerge thanks to the scientific worth accorded during the 1600's to the tools and instruments invented by man to overcome his limits. The new natural science came into being thanks to the invention and application to scientific ends of various tools which, by compensating for man's limited senses, permitted a new approach to the study of natural phenomena. Similarly the introduction of statistics surpassed the human mind's inability to quantitatively perceive and understand collective phenomena (originally limited to matters concerning the State and society).

Both the new natural sciences and statistics shared the same inductive empirical method, where the quantitative observation of facts and their theoretical elaboration by mathematics are inseparably linked.

Apart from the scientific goals set, both sciences pursued practical aims, thus

adopting a functional attitude to the reality under observation. The aim of science was to dominate nature to the benefit of mankind. The aim of statistics was good government and the public interest.

Italy in the 1600's was a leader in the natural sciences. This can be attributed to the many discoveries made by Galileo and his disciples. Italy also boasted the first scholars of modern mechanics, optics, astronomy as well as geography, medicine and botany. Italians, however, made little or no contribution to the origins and development of statistics, despite being forerunners in the field.

The reasons why Italians failed to make an active contribution to the budding social sciences could lie with the Counter-reformation and Inquisition. Both were responsible for curbing the country's intellectual freedom. The times were fraught with danger for any Italian scientist who attempted to challenge tradition and focus anew on the surrounding reality. Thus, a catholic scientist in Italy had no option but to avoid any clash with the ecclesiastical authorities and dedicate himself to a study of the natural sciences. These were looked on more leniently, as no challenge was made of existing Church doctrine. Any digression into other fields was to be discouraged. In such a climate any impulse to venture into the more risky area of the scientific investigation of human nature was quickly quenched.

La nascita della statistica e le origini della nuova scienza della natura

Riassunto

La statistica – intesa come metodo, che consente la conoscenza quantitativa dei fenomeni collettivi, e come scienza sociale – nacque dalla confluenza in un unico alveo di tre correnti di pensiero sorte, nel Seicento, in tre Paesi europei: la statistica descrittiva tedesca, l'Aritmetica politica inglese e la corrente francese che propugnava l'uso delle indagini statistiche e che quindi aveva come obiettivo la determinazione della loro metodologia. In quello stesso secolo fu creato in Francia il calcolo delle probabilità, che fu lo strumento matematico, indispensabile alla statistica. Sempre nel XVII secolo, si formò, per opera di Galileo Galilei, di Isaac Newton e di tanti altri scienziati, la nuova scienza della natura, fu anche inventata la macchina calcolatrice e furono poste le basi della matematica moderna con la creazione, oltre che del calcolo delle probabilità, della geometria analitica e dell'analisi matematica.

La nuova scienza della natura e la statistica, pur essendo relative a mondi diversi — quello dei fenomeni naturali per la prima e quello dei fenomeni riguardanti lo Stato e la società per la seconda — ebbero varie caratteristiche essenziali comuni o simili.

In particolare i processi di formazione di entrambe le scienze si basarono sui medesimi fattori e princÏpi e furono originati dalle stesse istanze ed esigenze. Le due scienze si poterono formare perché nel Seicento fu dato valore scientifico agli strumenti creati dall'uomo per vincere i suoi limiti. La nuova scienza della natura fu resa possibile, infatti, dall'invenzione o dall'uso a fini scientifici di apparecchiature che, superando le limitazioni dei sensi umani, consentirono. di indagare in modo nuovo i fenomeni naturali. Analogamente la creazione del metodo statistico, sopperendo alle limitazioni della mente umana di percepire quantitativamente i fenomeni collettivi, permise la conoscenza di questi fenomeni (originariamente soprattutto di quelli concernenti lo Stato e la società).

La nuova scienza della natura e la statistica si basarono poi sul medesimo metodo di conoscenza, il metodo empirico induttivo, in cui l'osservazione quantitativa dei fatti e

la loro elaborazione teorica, condotta mediante la matematica, si intrecciano inscindibilmente fra loro.

Entrambe le scienze, inoltre, perseguivano, oltre che obiettivi scientifici, anche finalità pratiche e perciò assumevano atteggiamenti operativi nei riguardi della realtà studiata: fine della scienza era quello di dominare la natura a beneficio dell'uomo; fine della statistica era il buon governo e il pubblico interesse.

Nel campo delle scienze naturali, l'Italia ebbe, nel Seicento, il primato, del quale furono artefici soprattutto Galileo, con le sue osservazioni e scoperte, e i suoi discepoli. In Italia si ebbero i primi cultori moderni di meccanica, di ottica, di astronomia ed anche di geografia, medicina e botanica. Nonostante ciò gli italiani non dettero, nel Seicento, alcun contributo alla nascita e allo sviluppo della statistica, pur essendo italiani molti precursori di questa disciplina.

Il motivo principale dell'assenza degli italiani dal processo di formazione delle scienze sociali può essere individuato nella Controriforma. e dell'Inquisizione che fecero perdere all'Italia la sua libertà intellettuale. I tempi erano infatti pericolosi per gli scienziati che, svincolandosi dalla tradizione, volevano studiare la realtà. E perciò agli scienziati cattolici italiani non rimase altra via che quella di evitare ogni dibattito con le autorità ecclesiastiche, le quali consentivano, ma fino che non fossero sorti contrasti con la dottrina adottata dalla Chiesa, alcuni studi nelle scienze naturali. Ma soprattutto negli altri campi era conveniente non esporsi affatto. Fu dunque questo clima a spegnere in Italia ogni impulso ad avventurarsi per i sentieri pericolosi dell'investigazione scientifica della società umana.

Key words

The origins of statistics; The history of statistics; The origins of the new natural science; The history of the new natural science.

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