Late scholastic probable arguments and their contrast with rhetorical and demonstrative arguments

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Abstract: Aristotle divided arguments that persuade into the rhetorical (which happen to persuade), the dialectical (which are strong so ought to persuade to some degree) and the demonstrative (which must persuade if rightly understood). Dialectical arguments were long neglected, partly because Aristotle did not write a book about them. But in the sixteenth and seventeenth century late scholastic authors such as Medina, Cano and Soto developed a sound theory of probable arguments, those that have logical and not merely psychological force but fall short of demonstration. Informed by late medieval treatments of the law of evidence and problems in moral theology and aleatory contracts, they considered the reasons that could render legal, moral, theological, commercial and historical arguments strong though not demonstrative. At the same time, demonstrative arguments became better understood as Galileo and other figures of the Scientific Revolution used mathematical proof in arguments in physics. Galileo moved both dialectical and demonstrative arguments into mathematical territory.

1. *The division of arguments into demonstrative, dialectical/probable, and rhetorical*

Aristotle's *Topics* opens with a division of arguments into three kinds: the demonstrative, the dialectical and the eristic or fallacious. The classification is essential to understanding his approach to argument and all developments in logic up to early modern times.

Aristotle had written a book on demonstration, the *Posterior Analytics.* A true or fully developed science should demonstrate its truths by syllogistic deduction from self-evident first principles, explaining why the truths of the science must be as they are. The first principles should be simple enough to be evident to the pure light of reason, or *nous* (Latin *intellectus*), a divinely-granted faculty of the soul capable of grasping necessities (Bronstein 2016: ch. 4).

If to modern ears that seems a promise too good to be true, for ancient, medieval and early modern thinkers it was confirmed by the existence and obvious success of Euclidean geometry, a science that seemed to conform exactly

philinq X, 2-2022, pp. 99-116
ISSN (print) 2281-8618-ETS doi: 10.4454/philinq.v10i2.424

to Aristotle's model (McKirahan 1992: ch. 12). Geometry was conceived to be a body of necessary truths about the real space we live in, not some Platonic abstraction of it. Attempts to cast other bodies of knowledge into the Euclidean mold proved less successful, but the model remained an ideal for them.

The meanings of the other two divisions of argument are less clear. To call an argument eristic or fallacious or "merely rhetorical" is to classify it psychologically rather than logically – it is said to have force in actually persuading listeners when it does not deserve it logically (or rather, independently of any logical force it may happen to have). As Aristotle puts it, an argument "is persuasive (*pithanon*) because there is someone whom it persuades" (*Rhetoric* 1356b29-30). However, Aristotle's *Topics* and *Rhetoric* and later works by leading theorists such as Cicero and Quintilian in fact disapproved of deliberately fallacious arguments and devoted considerable attention to kinds of argument which persuade because they do have logical strength. Nevertheless, the emphasis in later works of rhetoric was principally on techniques for rendering arguments attractive to hearers rather than on their logical force.

The profile of the middle classification, dialectical or probabilistic arguments, suffered because Aristotle did not write a book about them. The medieval and early modern (and even late modern) development of a theory of such arguments was therefore slow and painful. However, by the late Renaissance, there was some generally-accepted theory.

It came to be accepted that arguments could be probable – of some logical force short of demonstration – for two different reasons (called by the Renaissance scholastics "intrinsic" and "extrinsic" probability [Schuessler 2019: 169-72]). An argument has intrinsic probability (to some degree, which could be high or low), if the evidence supports the conclusion. Guilt in a court of law is proved beyond reasonable doubt (or not) by the evidence given; a scientific theory is supported by observational evidence. A central argument form is reasoning "from what happens for the most part", as Aristotle puts it, now called the proportional syllogism or statistical syllogism or direct inference (Franklin 2001: 113, 116; Thorn 2012). Modern accounts of the nature of such reasoning often start with the view of Keynes' *Treatise on Probability* that it is a kind of partial implication (Franklin 2011; Keynes 1921).

On the other hand, an argument has extrinsic probability if it is supported by respectable testimony or authorities. That is the kind of "dialectical" reasoning that Aristotle takes as a paradigm:

> Reasoning is dialectical which reasons from generally accepted opinions (*endoxon*)… *Endoxa* are those which are agreed to by all or most or the wise, that is, to all of the wise or most or the most notable and distinguished of them. Reasoning is eristic if it is based on opinions which appear to be *endoxa* but are really not so… (*Topics* 100a30-b25).

The important role in the Aristotelian tradition played by such arguments from authority opens the way for caricatures of that tradition as an ossified repetition of past authorities, unwilling to look at new evidence and arguments. While that was sometimes true, some skepticism may be entertained about the more extreme versions of that caricature such as that of Pascal's *Lettres provinciales* (Franklin 2001: 97-100).

2. *The late medieval development of probable arguments in law, moral theology and finance*

The period from the twelfth to the fifteenth century saw considerable expansion in the understanding of probable evidence, which formed the context of Renaissance and early modern theorizing. A theory of probable argument developed most centrally in law. That is natural as the essence of law, in the Western tradition derived from Greek and Roman law, is to decide cases by a court publicly evaluating evidence for and against a claim. Evidence for the guilt of an accused person or concerning the authenticity of a document or disputed ownership of goods is typically conflicting and the conclusion not obvious. Even if some cases are clear, it is in difficult cases that the law must develop theory to explain the different strengths of evidence.

The rediscovery of Justinian's massive *Digest* about 1070 led to centuries of development of legal theory in both civil and canon law (less so in English law). Around 1200 the school of Glossators in civil law devised the concept of "half-proof" to cover a single witness (given the biblical rule that two witnesses meant full proof) and partial documentary evidence, while canon lawyers graded presumptions as light, medium or probable, and violent. Conviction in criminal cases was to be on "proofs clearer than light", but, as with modern proof beyond reasonable doubt in Anglo-American law, that was a standard short of deductive truth. The school of Postglossators in the fourteenth century produced an elaborate codification of the theory of grading of evidence, with the works of Baldus de Ubaldis especially being in their printed versions foundational for (continental) law throughout the Renaissance (Franklin 2001: ch. 2). That was especially significant as law occupied a larger part of culture than later, so that many of the intellectual leaders of the early modern world had legal backgrounds: Copernicus, Bacon, Fermat, Huygens, de Witt and Leibniz were lawyers, Montaigne a judge, Valla a notary, Machiavelli, Cardano, Pascal and Arnauld the sons of lawyers, and Petrarch, Rabelais, Luther, Calvin, Donne and Descartes former law students. The tradition-bound culture of law also promotes the transmission of new developments, which are rarely lost.

These conceptual developments overflowed into Catholic moral theory, where the confessional was regarded as a miniature court of canon law and hence manuals for confessors advised on theory applicable to deciding "cases of conscience". Based on Aristotle's saying that less certainty was appropriate in ethics than in mathematics, "moral certainty" (*certitudo moralis*) was said by Gerson (c 1400) and later authors to be a grade of certainty short of deductive or mathematical certainty, but sufficient for confident action in practical matters (similar to "practically certain" in modern English). Debate also arose about what was permitted in case of doubt about the rightness of an action, for example in case of conflicting reasons or authorities. Medieval views were generally "tutiorist", suggesting a risk-averse attitude to possible sin, or "if in doubt, don't". However, as in legal cases, entertaining merely possible doubts made for excessive scruples and was likely to stand in the way of taking necessary action (Franklin 2001: 64-69; Schuessler 2019: 46-55).

Canon law and moral theory clashed with business practice over usury, and the debate about whether payments for risk constituted usury led to important conceptual developments in understanding the nature of risk. Maritime insurance, invented around 1350, reduced or "insured" risk by compensation for loss in return for paying a premium in advance; the premium charged thus involves an estimate of the probability of loss of the ship. It was understood by legal and moral theorists that purchasing risk as an entity separate from the thing at risk involved quantifying a "hope", "peril" or probability (Ceccarelli 2020: ch. 6; Franklin 2021). Similar questions arose and were dealt with in the pricing of life annuities (which involve an estimate of the probable length of life of the buyer), pricing of options contracts, and estimates of the compensation owing for loss of future expected earnings. For example, about 1300 Peter John Olivi considered that in case of compensation for a worker's loss of limbs, "the depriver is required to restore only as much as the probability of profit weighs (*quantum ponderat probabilitas talis lucris*)" (Franklin 2001: 266).

Legal debates on determining the authenticity of documents provided tools that were applicable to the critical evaluation of evidence in historiography, although that was not well-developed in the later middle ages. The reputation of medieval histories for excessive credulity about historical myths and miracle stories is not entirely undeserved, but a start was made on skeptical evaluation of stories, such as in William of Newburgh's severe criticism of the implausibilities in Geoffrey of Monmouth's "history" of King Arthur and his forebears (Franklin 2001: 182-3). The best-known and most successful work in this genre was Lorenzo Valla's exposure of the Donation of Constantine as a forgery, leading to some acute observations by him on how to interpret historical evidence generally (Mori 2020). Similar ideas and vocabulary were found in discussions of conflicting interpretations of scripture (Caldwell 2017: ch. 2; Ghosh 2019).

In medieval works on logical and rhetorical theory, "dialectical syllogisms", in the sense of probabilistic arguments, sometimes appeared, but they were only occasionally connected with the probabilistic arguments of law and finance (Franklin 2001: 121-26).

3. *The late scholastic synthesis on probabilism*

While the Renaissance humanists and the seventeenth century vernacular philosophers and scientists like Descartes, Pascal and Locke have enjoyed a high profile in the history of ideas, at the time the intellectual world and university posts were dominated by their opponents, the scholastics. The disgruntlement of the "new men" expressed itself in persistent criticism of the scholastics' alleged intellectual decrepitude and resistance to change. While that criticism was sometimes justified, as a general judgement this propaganda of resentment need not be taken with total literalness four hundred years later. In their areas of strength, the late scholastics were responsible for conceptual innovations essential to modern thought.

Their strength lay not in observational or experimental science, but in disciplines that require a high level of conceptual analysis – of which probability theory is a central example (overview in Franklin 2012). So chemistry and biology were outside their range, but economic, legal and political theory and linguistics were their home territory. Well-known examples of their work include the contributions of the "School of Salamanca" to the analysis of economic concepts like demand, utility and opportunity cost (Langholm 1998), constitutionalism in political theory that opposed absolute monarchy (Lloyd 1991) and the foundations of international law (Scott 1934, Amorosa 2019). In more strictly scientific areas, they contributed to the analysis of continuous variation that led up to the calculus of Newton and Leibniz (Boyer 1959: ch. 3) and to faculty psychology (Harvey 1975). It was also characteristic of the scholastics to be universalists in knowledge – the most prominent theorists such as Francisco de Vitoria, Domingo Soto, Melchor Cano, Francisco Suarez, Leonardus Lessius and Juan Caramuel Lobkowitz wrote on and made substantial contributions to a wide range of topics.

Probability theory was a subject tailor-made to suit the strengths of the late scholastics, as it requires first and foremost a deep analysis of concepts – concepts that are not purely speculative but founded on understanding how reality works. Their analysis of probabilism in moral theory and of aleatory contracts in law laid the conceptual foundations of later probability theory, including the mathematical theory that stems from the 1654 correspondence of Pascal and Fermat that is usually taken to be the founding event of mathematical probability.

The first thing needed to become oriented in probability theory is to draw the distinction between logical or epistemic probability on the one hand and factual or aleatory or stochastic probability on the other. Logical probability refers to the logical relation of evidence to conclusion, such as in proof beyond reasonable doubt in law or the experimental evidence for a scientific theory; it has nothing to do with randomness or chance. On the other hand, aleatory probability refers to the outcomes of stochastic processes like throwing dice and coins or the random sinkings of ships. It is a matter of frequencies in the real world and the patternless sequence of random events, not to do with knowledge or uncertainty (cf. Franklin 2009: ch. 10; Hacking 2006: ch. 2). Of course there are some connections between the two – the randomness of coin tosses, a fact in the external world, induces uncertainty about future outcomes.

This distinction is implicit though not explicit in late scholastic work on probability. Epistemic probability is dealt with in the continuation of medieval legal and moral debates, leading to the moral doctrine of probabilism, while stochastic phenomena, including games of chance, are grouped under the classification of aleatory contracts. We will consider them in turn.

Renaissance legal theory produced some massive works on presumptions, such as those of Menochio and Mascardi, but little advance in concepts (Franklin 2001: 43-6). The main development came in moral theory concerning action in case of doubt, where medieval tutiorism was generally superseded by the laxer doctrine of probabilism, enunciated by Bartolome de Medina in 1577. It held that in case of doubt about a course of action because there are reasons and authorities on both sides, one might follow a course that is probable, even if the opposite is more probable. “Probable” here means being supported by substantial reasons and/or authorities (something like English “arguable”), rather than “more likely than not on the balance of evidence”, so the position is at least meaningful. Nevertheless it is undeniably strange to regard it as permissible to follow a position which one believes is not the strongest on the available evidence (Franklin 2001: 74-6; Schuessler 2019: 78-85). Despite this, probabilism became near-orthodoxy in Catholic moral theory for the next century, giving Pascal a wide target to aim at in his attack on Jesuit moral theory in general in his *Lettres provinciales* of 1656-57 (Franklin 2001: 94-101; Maryks 2008). The wide currency of these debates ensured that some concept of (epistemic) probability was widely available in early modern intellectual life, well before the appearance of any mathematical theory of probability. Indeed, despite Pascal’s efforts, the vigor of scholastic debate on theoretical questions of probability, taking account of new developments in the wider world, continued into the late seventeenth and eighteenth centuries (Hanke 2019; Hanke 2020; Schuessler 2019: ch. 8).

Probabilism proved especially applicable to politico-ethical questions, whose nature involves sometimes deferring to the opinion of others (with which one may not agree oneself). Is it ethical to put aside one's own opinion on what is right and follow that of the majority, or the prince, or a committee? Should a soldier who doubts the justice of his prince's war refuse to fight in it, given that he knows the prince may be better informed and so have a more probable opinion? (Franklin 2001: 77-79; Schwartz 2013; Schwartz 2019: ch. 6). Given that dissension in councils prevents their effective working, is it acceptable for a member to defer to the decision of the majority although he disagrees with it? (Schwartz 2022). May a prince engage in normally immoral actions such as lying for "reason of state"? According to Jean de Silhon, advisor to Cardinal Richelieu, he should invoke reason of state, "a mean between that which conscience permits and affairs require", because the safety of the state is entrusted to him as a sacred duty. "In doubtful cases he [the minister of state] will always choose what is safest and most advantageous to his master even though the least probable, provided that it is truly probable. In this, he combines two maxims, one of conscience and the other of prudence" (Franklin 2001: 80-81). If one finds advanced civilizations with different religio-philosophical views, such as the Chinese, can one grant those views some kind of provisional acceptance? (Mayer Celis 2015).

In principle, these debates on the grading of probabilistic reasons in law and moral theory could have been applied to evaluating the strength of reasons for factual theses, such as scientific and historical theories. That was not commonly done, but some examples exist. An application to the credibility of the Copernican hypothesis was made by Galileo, as we will see below. In historiography, the leading writer was the Spanish scholastic Melchor Cano.

Cano died in 1560, before Bartholome de Medina's enunciation of probabilism, but in his writings on moral theory he shows similar tendencies to take the conflict of probable reasons and authorities to deliver liberty to the subject who is in doubt about what to do. When there are different probable opinions of doctors on the licitness of contracts – as was typically the case with the complex contracts available in business – Cano holds that either choice is safe (otherwise "all human contracts would cease, provisions necessary to human life would not be made, and republics and provinces would be laid waste"). He comes close to probabilism in holding that one may act against one's own opinion if the opposite course is still safe, though the first course may be safer. Indeed in some cases "it is more probable that a man not only can, but should, act contrary to his own opinion when he considers the other probable". A confessor, for example, should absolve a penitent whose opinion is probable but contrary to the confessor's (Franklin 2001: 74).

Cano's originality lies in applying ideas about probability to a systematization of methods for evaluating the reliability of historical texts, a central topic of his posthumous work on the sources of theology, *Loci theologici* (1562). Giuliano Mori writes "Probability emerges as Cano's core concern. Along with the cognate concepts of credibility, verisimilitude, and plausibility, the notion of *probabilitas* is mentioned no less than 216 times in the *Loci*. Indeed, Cano's entire treatise can be read as an attempt to devise a probative organon where the *loci* are critically discussed and compared with one another, being ultimately placed upon a scale of generally decreasing probability". Cano's development of these ideas, which makes him the central figure in early modern theory on evaluating historical evidence, is described in Mori's article in this issue (Mori 2022).

4. *The late scholastics on aleatory contracts*

The scholastics rightly separated their treatment of the probability of opinions from their treatment of aleatory contracts. The background to the latter lies in the developing risk culture of business. In the Renaissance, a culture of high risk and more explicit discussion of risk met the abilities of the late scholastic schools in conceptual analysis.

Many observers have noted a "risk culture" as increasing in many spheres in the fifteenth century and later. Any business or financial undertaking was by later standards extremely dangerous and recognized to be such (Baker 2021). Even in the art world, both granting and accepting a commission was attended by multiple risks, for example of dissatisfaction on either side (Nelson and Zeckhauser 2008). But the paradigm of a risky enterprise was a sea voyage, as used for dramatic effect in Shakespeare's *Merchant of Venice*, where Antonio the merchant is easily ruined by the nonarrival of his ships. Shakespeare explains the willingness of some to accept low odds for the chance of high gain:

> We all that are engagèd to this loss
> Knew that we ventured on such dangerous seas
> That if we wrought out life, 'twas ten to one;
> And yet we ventured, for the gain proposed
> Choked the respect of likely peril feared (*Henry IV*, part 2, Act 1 Scene 1).

Those numerical odds may be no exaggeration. Sailing into the unknown with Columbus, da Gama or Magellan offered scarcely better odds of return than that.

The late scholastic commentators on legal and moral theory correctly recognized a category of aleatory contracts, where a contract is undertaken whose outcome depends on some chance event. The category included insurance contracts (usually maritime insurance), life annuities, purchase of options and games of chance – in each case, the parties agree beforehand on the terms, but what the contract requires depends on chance events such as the return of a ship, the time of death of an annuitant, or the fall of the dice. Some numerical estimate might be made of those chances, as is done in deciding the premium of an insurance or the stakes in a fair game of chance. But it is hard to know how to make those estimates, and even if they are correctly made, chance determines the actual outcome.

The clarity of understanding reached by the scholastics in these matters is illustrated by Cano's Spanish contemporary, Domingo Soto. In answering the objection that insurance appears to involve a payment for nothing, he compares it to a game of chance:

> For anything that can be estimated at a price, one can receive a fee: to render a thing safe [insure it], which is exposed to peril, can be estimated at a price… we say of a fair game: whether it will rain tomorrow or not, etc.; so in the same way it is permitted to expose a thousand ducats, say, to peril with the hope of making fifty or sixty. There are some who regard it as stupid to allow the peril of someone's ship worth perhaps twenty or thirty thousand, in the hope of making a hundred or a thousand. To this we reply that it is not for us to dispute about prices: these can be just or unjust, but it is for the contracting parties to decide them. But there is no stupidity or folly in accepting this kind of peril at the going price; in fact nothing is more obvious than that insurances can expect to gain. They may lose sometimes, but at other times they accumulate gain (Soto 1569, bk 6 q. 7; Franklin 2001: 286).

That is correct not only in understanding the common nature of insurance and games of chance, but in appreciating that chance in the individual case can even out in the long run, so that insurers make money on average although they can lose in individual cases.

One particular kind of aleatory contract had a low profile in discussion as well as a bad moral reputation, but was to prove conceptually important – games of chance. Lotteries, betting and games of chance also came to attention as a different kind of paradigm of risky decisions – one that might be, though with difficulty, amenable to some kind of exact numerical calculation (Franklin 2001: 278-85, 296-301). Their nature however is quite unlike insurance and annuities which are inductive – the correct prices for insurance and annuities depend on past data (of rates of shipwreck and mortality), whereas the throw of the dice deletes all history and the probabilities of the outcomes depend solely on the symmetries of the faces (and any biases). That makes dice a poor model of most probabilistic reasoning – but is a great mathematical convenience, allowing the development of an exact mathematics of probability (in the sense of history-less stochastic processes) in the correspondence of Pascal and Fermat in 1654.

5. *Scientific reasoning in Galileo: Probable and demonstrative arguments take on mathematical form*

Galileo's achievements included not only strictly scientific discoveries about astronomy and motion but a new method for explaining and defending conclusions in the natural sciences. The standard scholastic method of disputed questions with all kinds of arguments allowed on both sides of a question, including arguments from authority, he found to be inadequate and worthy of mockery. His replacement was however not much like the modern model of scientific method according to which hypotheses generated by any method or none are confronted by observational and experimental tests and either confirmed or falsified. Instead it was a combination of dialectical (in the sense of probabilistic) and demonstrative reasoning, but with both of those given more mathematical form than had been traditional.

The Jesuits, by 1600 leaders in the world of academic science, applied the scholastic method to astronomical questions, treating them as if they were problems of canon law or moral theology. The following passage, written about 1590, is typical of the style of argument; it is the same style as found in, for example, the debates on probabilism, with its mixture of considerations of plausibility and appeals to religious and other authority. It is worth quoting at some length, to convey the exact consistency of the intellectual bog from which modern science had to extract itself.

> Fourth question: Are the heavens incorruptible?
>
> The first opinion is that of Philoponus… since the heavens are a finite body, if they were eternal they would have an infinite power… it seems that Holy Scripture teaches generally that the heavens are corruptible, especially Isaiah ch. 51, "the heavens shall vanish like smoke", and 34, "the heavens shall fold up like a book"…
>
> The second opinion is that of Aristotle, who was the first, as Averroes notes, to teach in this book that the heavens are ungenerated and therefore incorruptible… Finally, the intelligences achieve their perfection in moving the heavens, and so the heavens must be incorruptible.
>
> For the solution of the difficulty, note that in truth we can speak of the heavens, just as we can of anything created, in two ways: first, from their very nature, whether, namely, they have by their nature some intrinsic principle through which they can be corrupted; second, whether only through the absolute power of God, whereby God

can make everything return to nothing, they are corruptible… the Council of Constance defines that angels and human souls are immortal by divine grace…

I now say, first: if we speak of the heavens according to their nature, and if corruptible be taken to signify anything that has in itself a passive potency whereby it can be corrupted by an active power proportioned to it, it is probable that the heavens are corruptible…

Second proof: because the heavens were made especially for man; therefore they ought not to be incorruptible, for otherwise they would be more noble than man…

I say, second: it is more probable that the heavens are incorruptible by nature. Proof of this, first: because it is more conformable to natural reason, as is apparent from the arguments of Aristotle… The second argument of Aristotle is drawn from experience: for it has been found over all preceding centuries that no change whatever has taken place in the heavens. And this argument has the greatest force… A third argument is drawn from the consensus of all peoples… Fourth, from the etymology of the word… (Wallace 1977: 93-99).

What is surprising is that the author of this rubbish is the young Galileo himself. It is from unpublished notes, which have been found to be a collage of the lecture notes of a number of Jesuit professors at the Collegio Romano, dating from the late 1570s and the 1580s. These professors made considerable play of probabilities and their comparisons, in the same way as the passage just quoted. Galileo later wrote:

If what we are discussing were a point of law or of the humanities, in which neither true nor false exists, one might trust in subtlety of mind and readiness of tongue and in the greater experience of the writers, and expect him who excelled in those things to make his reasoning more plausible, and one might judge it to be the best. But in natural sciences whose conclusions are true and necessary and have nothing to do with human will, one must take care not to place oneself in the defense of error; for here a thousand Demostheneses and a thousand Aristotles would be left in the lurch by every mediocre wit who happened to hit upon the truth for himself (Galileo 1967: 53-54).

Plainly the scholastic *quaestio* was not working well as a vehicle for scientific arguments.

Galileo proposed to re-establish science, in particular physics and astronomy, on a sound basis. His counterattack was two-pronged. In his more popular pro-Copernican *Dialogue Concerning the Two Chief World Systems*, he developed probable arguments in a style that eschews arguments from authority but develops the scholastics' "intrinsic probability". In his more fundamental work on dynamics, *Discourses and Mathematical Demonstrations Relating to Two New Sciences*, completed in old age during his house arrest by the Inquisition, he revived the Aristotelian ideal of demonstration, but enhanced by mathematical proof. We will examine these in turn.

As Nicholas Jardine shows (1991), Galileo's 1632 *Dialogue*, written in Italian for a lay audience, is a self-conscious amalgam of demonstrative, dialectical and rhetorical argument. Galileo is well aware of which he is using at any point and what form of expression is appropriate to each. He claims demonstrative certainty for his refutations of his Aristotelian opponents' arguments against the motion of the earth and for his argument that the tides need a Copernican explanation; however, his demonstrative arguments are more mathematical than most previous discussions, which tended to keep separate arguments on the nature of celestial bodies from mathematical calculations of orbits. His rhetorical strategies of praise and blame, jokes, parodies and misrepresentations of his opponents are standard devices of Renaissance rhetoric; they include the old trope of dismissing opposing arguments as "mere rhetoric" (Jardine 1991, section VII; Vickers 1983). Dialectical arguments are particularly prominent, and well-suited to the dialogue form that permits the arguments on both sides of a question to be stated as strongly as possible and balanced.

One of Galileo's probabilistic arguments for Copernicanism, is, like his demonstrative arguments, more quantitative than anything that went before. It is an example of what are now called extrapolation arguments or Mill's "Method of concomitant variation", which argue that a pattern visible in some region (of space or time) can be expected to continue to hold true outside that region (but less reliably, the farther the extrapolation goes beyond the observed region [Franklin 2013b: section 2]).

Galileo is arguing that the Copernican system has spheres moving more slowly the farther they are from the sun, whereas the Ptolemaic system has to break that pattern suddenly by having the most distant sphere, that of the fixed stars, rotate once a day. His argument includes parallels with the orbits of the moons of Jupiter, recently discovered by himself, as well as with the long-known orbits of the planets:

> The improbability is shown for a third time in the relative disruption of the order which we surely see existing among those heavenly bodies whose circulation is not doubtful, but most certain. The order is such that the greater orbits complete their revolutions in longer times, and the lesser in shorter: thus, Saturn, describing a greater circle than the other planets, completes it in 30 years; Jupiter revolves in its smaller one in 12 years, Mars in 2; the moon covers its much smaller circle in a single month. And we see no less sensibly that of the satellites of Jupiter the closest one to that planet makes its revolution in a very short time, that is in about 42 hours; the next, in three and a half days; the third in 7 days and the most distant in 16. And this very harmoni-

ous trend will not be a bit altered if the earth is made to move on itself in twenty-four hours. But if the earth is desired to remain motionless, it is necessary, after passing from the brief period of the moon to the consecutively larger ones, and ultimately to that of Mars in 2 years, and the greater one of Jupiter in 12, and from this to the still larger one of Saturn whose period is 30 years – it is necessary, I say, to pass on beyond to another incomparably larger sphere, and make this one finish an entire revolution in twenty-four hours (Galileo 1632/1967: 118-19).

Remarkably, Galileo's scholastic opponents were capable of replying with an argument of the same form. The Jesuit Amicus suggested that though the earth was smaller than the heavens, it was heavy, and as water was more mobile than earth, air than water, and fire than air, so the celestial bodies were more suited to motion in their place than the earth in its (Grant 1984: 58). It is by no means unreasonable to think that a very distant sphere made of a weightless quintessence might revolve in twenty-four hours more easily than a massive solid earth that would be expected to shake violently and throw off the objects on its surface.

In another clear case of quantitative probabilistic reasoning, Galileo showed how to fairly adjust error-prone astronomical observations to reach a correct conclusion on the distance from the earth of the nova of 1572 (Franklin 2001: 160-61). The debates showed the successful movement of probabilistic argument into the domain of quantitative sciences, the area in which the Scientific Revolution was to transform the world of ideas.

Galileo's demonstrative reasoning, like his dialectical reasoning, was more mathematical than what had gone before. He was the first (except for Stevin) of a line of seventeenth-century thinkers who applied mathematics to physics – Descartes, Pascal, Huygens, Barrow, Newton and Leibniz, to name the most prominent. They were captivated by the Aristotelian/Euclidean demonstrative model of science as applicable not just to the abstract world of pure mathematics but to applied mathematics. It was apparently realized in Euclid's *Optics* and Archimedes' mechanics, according to which pure thought could establish principles for empirical reality (Franklin 2017).

The story of seventeenth-century applied mathematics is more like an extension of scholasticism (in a mathematical direction) than a retreat from it (into for example Baconian empiricism). Where the old scholastics had been excessively modest about the possibilities of reducing the contingent physical world to quantitative order and demonstration, the mathematicians showed it could be done by doing it. Early modern applied mathematics is the pursuit of the Aristotelian-scholastic vision by other means.

While optics and statics were the two most successful inherited models of applied mathematics, the one most important for later developments was dynamics, the study of motion and its causes. That was the field which was to contain the most central developments of the late seventeenth century, the calculus of Newton and Leibniz and Newton's gravitational theory. The Merton School and Nicole Oresme in the fourteenth century had made important initial progress in distinguishing speed from acceleration, in proving the "Merton mean speed theorem" that connected uniform acceleration with distance travelled, and in inventing graphs of functions (Boyer 1959: ch. 3; Sylla 1986). But thereafter progress stalled for over two centuries. Galileo restarted progress with his discovery of the uniform acceleration of heavy bodies dropped from rest.

In the course of that discovery Galileo provided an astonishing demonstration of the power of a priori mathematical reasoning to give insight into the behavior of physical reality, independently of observational evidence. When first considering what law should be followed by falling heavy bodies, once it is accepted that they go faster as they fall, he wondered about how to distinguish between the two simplest theories: the perhaps most natural one that speed is proportional to distance travelled from the start, and the equally simple but perhaps less natural one that speed is proportional to time from the start (that is, the body is uniformly accelerated, which is the correct answer).

Galileo realized, and was able to demonstrate, that the first theory needs no observations to refute it. It is absolutely impossible that acceleration should be proportional to the distance travelled. Galileo argues thus:

> When speeds have the same ratio as the spaces passed or to be passed, those spaces come to be passed in equal times; if therefore the speeds with which the falling body passed the space of four braccia were the doubles of the speeds with which it passed the first two braccia, as one space is double the other space, then the times of those passages are equal; but for the same moveable to pass the four braccia and the two in the same time cannot take place except in instantaneous motion (Galileo 1638/1974: 160; Norton and Roberts 2012).

That reasoning is less than totally clear and would be assisted by a diagram (provided in Franklin 2017).

From the falsity of the theory of the proportionality of speed to distance there does not follow, of course, the truth of the (true) alternative theory of the proportionality to time. But it leaves that theory as the most natural simple alternative, guiding the effort of empirical confirmation. Galileo has shown, in the fashion of Aristotle's *Posterior Analytics*, that purely mathematical reason has implications for what can possibly be observed in physical reality.

Both dialectical and demonstrative reasoning were central to the scientific awakening in the modern world, but in forms newly clothed in mathematics.

6. *Conclusion: The scholastics and quantitative probabilistic argument*

To appreciate how Renaissance and early modern authors understood the evaluation of uncertain evidence, certain revisions to received ideas of intellectual history are needed. Firstly, it requires taking seriously Aristotle's category of objectively weighty dialectical (or probabilistic) reasons. They are neither deductive arguments nor of merely rhetorical of psychological force, but give substantial logical support for conclusions, short of proof (in law, science or whatever their subject matter may be). That category of argument has a history, just as deductive logical argument and rhetoric do, but it needs to be disentangled both from those two subjects and from the history of the particular topics of such arguments (such as law or moral theory).

Secondly, it requires taking seriously the late scholastic tradition as the intellectual leaders in many fields into the seventeenth century, free from any after-effects of the anti-scholastic propaganda of humanists and of early modern philosophers writing in the vernacular. In fields where progress could be made by conceptual analysis, such as argument forms and probability, the scholastics remained in the forefront of intellectual progress.

Thirdly, it requires taking seriously the better understanding of the possibilities of mathematics, as first revealed mainly by Galileo. He showed that in the analysis of both motion and the force of arguments, attention to continuous variation and its quantification could advance the project of Aristotle's *Posterior Analytics*, of demonstrating certainties present in the real world and allowing the human mind to understand why they must be so.

With those revisions in place, we can see that the late scholastic theory of probable arguments was one of the leading achievements of early modern thought.

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