

Pascal's legacy

The musings of a Belgian monk 300 years ago on the consequences of believing in God, or not, have influenced our Western life probably more than any other scientific or technological invention

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When whizzing across town in a car or jetting across the continent in an airplane, the miles racing by, it is easy to appreciate how these two inventions have changed our lives. So, too, did the telephone and the computer, steel and reinforced concrete, the polio vaccine and DNA sequencers. It is more difficult to measure the impact of the non-material, intellectual contributions of science over the past several centuries: the insights of Copernicus that shifted the earth from the centre of the universe to a mere planet orbiting the sun, Darwin's theory of natural selection and the subatomic world described by quantum mechanics. Nevertheless, they all greatly influence our view of the world and have left lasting impressions on society.

One little-heralded revolution in science and mathematics that began in the seventeenth century, however, has changed the dynamics of our daily lives even more profoundly. When Blaise Pascal (Fig 1), an eccentric French monk, fiddled around with some simple but startling observations that would eventually mature into probability theory, he was letting the proverbial genie out of the bottle. Probability theory and the discoveries following it changed the way we regard uncertainty, risk, decision-making, and an individual's and society's ability to influence the course of future events. Although this revolution has contributed to most of the marvels of the modern age, it has also introduced a host

of new challenges and incumbent dangers as well as creating confusion, alienation and suspicion of modern science among much of the public.



Fig 1 | An engraving of Blaise Pascal (1623–1662), Belgian mathematician and monk, after a seventeenth-century French painting. © Stefano Bianchetti/CORBIS

Pascal's interest in probability came about when a man presented him with a puzzle. The Chevalier de Mere, a noted *bon vivant* and an ambitious gambler, dabbled in mathematics to increase his returns, mostly putting his hunches to work in the gambling parlours of Paris. His love of games of chance prompted him to bring a two-centuries-old brainteaser to Pascal who, in turn, conferred with mathematician Pierre de Fermat, he of 'last theorem' fame. The 'problem of the points' involved two players in the midst of a series of dice games, winner takes all. One is winning, but the match is broken off before it is finished. How does one equitably split the prize money? Pascal dismissed the solution that called for an even split of the purse because it did not adequately reward the person who was ahead. Nor would giving all the money to the person who was ahead adequately acknowledge the possibility that, should the series be completed, the losing player could come from behind and win. Pascal realized that the answer lay in determining each player's odds of winning and turned to a device already in use: numbers arranged into tables according to the mathematician's purpose. Pascal's arrangement to find a solution took the shape of a triangle, now named after him (Fig 2). Using it, one can calculate the odds of winning the series at any point during the contest. But the real beauty of Pascal's achievement lies in its recognition that mathematical principle, not just the bettor's hunch, could be applied to

figuring out the odds in a game of chance. Here was the very idea of probability: establishing the numerical odds of a future event with mathematical precision. Remarkably, no one else had cracked the puzzle of probability before, although the Greeks and Romans had come close.

By all accounts, Pascal was an odd fellow. He spent much of his short adult life torn between his love of mathematics and science, and the world of the ultra-strict Jansenists, a fundamentalist Catholic sect. The year 1654 proved pivotal for Pascal. Poor health, bouts of depression and a series of disappointments left him increasingly frustrated with secular life. One day, his team of horses bolted while crossing a bridge at Neuilly. The force and suddenness of the movement broke the harnesses, and the horses plunged over the edge of the bridge. A breathless Pascal sat immobile on his now horseless carriage, which remained atop the bridge. The frail genius attributed his miraculous escape from death to divine intervention and saw it as a sign that he should embrace religion. He sold his possessions and, at 31, moved to the monastery at Port-Royal-des-Champs, near Paris, to take up the Jansenist life. Before he died eight years later, Pascal went on to publish several important religious treatises. But what attracts our attention today are two pieces of paper, each covered front and back with handwriting scribbled in all directions, on which he took the same principles of probable outcomes that he had worked out with Fermat for the dice games and applied them to an entirely different matter.

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He asked: "God is, or he is not. Which way should we incline?" Reason, Pascal knew, could never establish definitively whether God exists. Pascal deduced, however, that the act of believing in God could have two outcomes, depending on whether God exists. If God does not exist, nothing

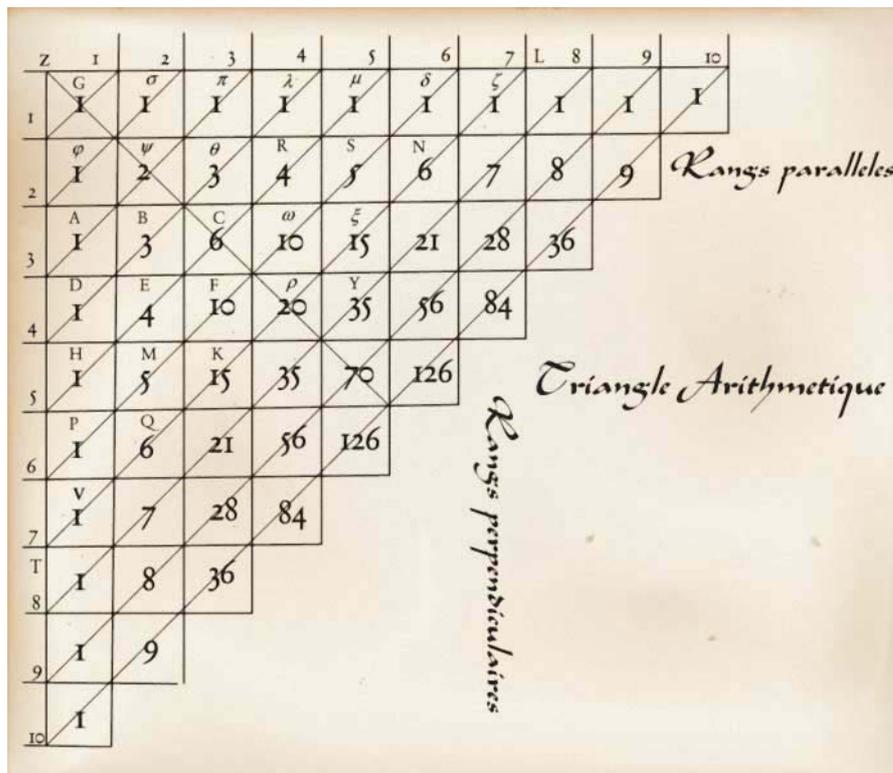


Fig 2 | Pascal's arithmetical triangle for the calculation of probabilities

will happen to the believer. If God does exist, the believer will be blessed with eternal salvation. The non-believer also faces two possible outcomes. If God does not exist, he will suffer no consequences. If God does exist, the non-believer will face eternal damnation. The non-believer faces either no consequences or hell; the believer, no consequences or heaven. Faced with heaven or hell, Pascal reasoned, it makes sense to open oneself to faith.

Although later philosophers have criticized the reasoning for both its premises and its cynicism, Pascal's logic remains solid. While gamblers of all eras have picked up much about basic probabilities from experience and intuition, the power of Pascal's new theory took the understanding of odds a major step forward. Importantly, Pascal also took the grand leap of applying this logic to situations outside gaming. This work would become the basis for decision theory, defined by historian Ian Hacking as the "theory of deciding what to do when it's not certain what will happen." Pascal's wager is the very essence of modern-day risk analysis and management: evaluate the consequences of individual and group actions, measure them and, in turn, make better decisions.

The word 'risk' entered the English lexicon at about the same time as Pascal worked with probability theory during the mid-seventeenth century. Not once did William Shakespeare, who died in 1616, use the word in his plays or poetry, although the bard certainly understood the concept behind it as used today—the idea that an activity or event could result in the possibility of loss or harm. Of course, Shakespeare, Alexander the Great, or a medieval knight preparing for a joust, all understood perfectly well the consequences of their actions, regardless of whether or not they used a specific word to describe it. No one needed to understand probability theory to know that different courses of action could change the outcome of a dangerous situation. Shakespeare rather used the word 'hazard' more than three dozen times in his plays. "Men that hazard all," says Morocco to Portia in *The Merchant of Venice*, "do it in hope of fair advantages." The verb 'to hazard', which means to venture, is derived from an Arabic dice game *as-zahr*. Taking the other meaning of 'hazard'—a source of danger—the difference between 'hazard' and 'risk' may seem slight or semantic.

However, the distinction between the two reveals how significantly our worldview has changed since Shakespeare's time, largely due to Pascal's theory of probability. 'Hazard' refers to an activity or technology that poses a threat to humans and what they value. By contrast, the more abstract concept of risk centres on the possibility—or probability—of that hazard or danger being realized. Within this province of possibility and uncertainty lie some of the most vexing questions facing human beings.

Other thinkers took Pascal's work further and developed more tools with probability, from discovering correlation and regression, to sampling and the bell curve. Their insights into probability enriched a civilization exploding with new information about the way the world worked. During the Renaissance, revolutions in science, religion and political theory and the emergence of democratic institutions freed individuals to think about themselves as free-acting entities, able to exercise control over their futures. Science began to reveal that events and conditions once attributed to gods or magic were caused, in fact, by tangible natural forces and substances or by chance, in a quantifiable way. Probability, it now appeared, was woven into the fabric of the universe. Freed from the yoke of a deterministic worldview, humans could take bold steps to vanquish hazards that had long plagued them. With these new perspectives and a growing arsenal of mathematical tools, human beings took great strides toward controlling and manipulating the future in the form of risk-management strategies. By better understanding the likelihood of an event's future occurrence, scientists began to examine the shape of the future itself, the closest thing to looking into a crystal ball that humankind is ever likely to have. In many forms, probability and statistics have played a crucial role in all the advances that have brought us longer lives, better standards of living and less vulnerability to the ravages of nature. They remain among the most powerful intellectual tools that humankind has ever invented.

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The ability to describe the probability of some future event with numbers—a percentage, for instance, as in "a 40% chance of rain"—makes it possible to compare the severity or frequency of one risk with another. If the expression of risk could be defined in the universal language of numbers, then a person could compare the annual chances of being killed by a shark attack in the USA (1 in 2,720,000) versus the odds of being struck by lightning (1 in 5,787,000). In fact, just about any potential risk could be compared with another if enough data were available. Using vast archives of stored data about past events, a person with a calculator and rudimentary mathematics skills can calculate the odds of virtually anything happening to him or her in the future.

It is odd to think that the musings of a brilliant monk 300 years ago would eventually cause me to lie in my bed one gloomy morning worrying about whether I should get up or not. As I lay there, the risks of my day spread out before me like a medieval gauntlet with no end in sight. First thing every morning, I usually turn on the old green metal standing lamp that once belonged to my wife's grandmother. From reading over the past few months, I recall that each year at least 60 Americans electrocute themselves on domestic wiring and appliances. I calculate my odds over a year as 1 in 4,000,000.

My trip to the bathroom half asleep holds risks, too. Each year, nearly 2,000,000 Americans hurt themselves badly from slipping and falling in the home, and 8,500 people die from these falls. I compute my personal risk of dying from a fall as about 1 in 30,000, although my actual chances are less because I am younger than 70 and healthy. If I make it safely to the bathroom, I know from my research that I must approach the toilet and sink warily. They injure more than 60,000 Americans annually (my odds: about 1 in 4,500). The shower claims nearly 170,000 injuries every year, shaving hurts another 40,000. I stand a 1 in 7,000 chance of cutting myself badly enough with my razor this year to seek medical attention. And, if I cut myself slightly, I cannot afford to become angry. Some studies suggest that getting mad increases my chances of having a heart attack.

Even the act of getting dressed places me at risk. Zippers, buttons and other articles of clothing hurt more than 140,000 Americans

each year. Jewellery sends some 55,000 to the doctor or clinic. When I open my wallet and count my change, I am reminded that half of the paper currency and coinage in our pockets carries infectious germs. According to National Safety Council statistics for 1996, I have a 1 in 36 chance of becoming disabled for a day or more by an unintentional injury sustained at home.

These thoughts were enough to convince me that maybe it is safest to stay in bed. But then other facts pop into my slowly awakening consciousness: literally, lying in bed is risky. The headboard could collapse or I could fall out of bed. Each year, beds, mattresses and pillows injure more than 400,000 Americans. Also, sociologists have compiled risk information indicating that unemployment—what I face if I stay in bed—is bad for my health, placing me at higher risk for high blood pressure, high cholesterol, heart problems and more. Another couple of minutes in bed surely wouldn't hurt, I rationalize. My thoughts of an amorous interlude with my wife bring to mind a recent study in the *Journal of the American Medical Association*. Passing from a relaxed state quickly to the strenuous exertion of passion can shock my body, raising my chances of a myocardial infarction by 1 in 1,000,000.

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This outlook on my morning may seem paranoid. Indeed, it probably arises from reading too many risk statistics. However, the fact that I can examine my morning ablutions so completely in the guise of risk is something new in human history. What is unusual is that I am able to quantify—put numbers on—the concern I have about my health and mortality. We have always lived in an uncertain world, but it is a new twist to view uncertainty and the hazards it contains in a sturdy, numerical context. A single fact, such as the risk of cutting myself shaving, means little on its own; taken altogether, however, the risk estimates, comparison and statistics that are now available force us to

look at our world with new eyes. The risk information in numerical form or couched in the specific lingo of probability—weather forecasts of rain squalls, a new health study reporting the correlation between indoor pollution and cancer, or the dangers of a particular stock portfolio—are the manifestation of a revolutionary change in how we think about uncertainty and risk.

It is up to us as individuals, and collectively as a culture, to make the judgements about what we will and will not tolerate

All the intellectual tools of probability theory lead us to one deceptively simple but quite profound revelation: any activity, product, food or event involves risk on some level or another. Every decision we make holds consequences: cross at the light or jaywalk, eat a healthy lunch or a hamburger, invest in the stock market or bonds. The work of Pascal and others that followed in his footsteps gives us today the possibility of seeing the world in terms of the rich range of consequences, and delivers the tools with which to evaluate them.

The average Westerner is only just beginning to recognize and understand the way in which we have begun to think about risk. Consider a few examples just in the arena of personal health: risks can result from action—from shaving to driving to hang-gliding—or occur passively, from breathing polluted air, exposure to radon, the expression of a genetic disease or getting randomly hit by a falling aircraft. The expression of risk can be immediate—having an accident in a car—or it can be a hazard that takes years to play out: melanoma caused by exposure to the sun that turns deadly after several decades. Risks exist either when an individual performs an action or if he does not. A sick man who heeds his doctor's advice to get a chest X-ray incurs risk when he cooperates—the drive to the office and the additional X-rays from the diagnostic test—or he faces the risk of the condition worsening and threatening his life if he does not. There are direct health risks, such as smoking cigarettes, more indirect but still serious 'risk factors' (high blood pressure), and a range of risk correlations,

such as cancer from mobile telephones. Negotiating this environment full of risks is a daunting task indeed.

Pascal begat a world in which individuals today can wield more power over their futures than ever before. At the same time, we are forced to make increasingly complex and difficult decisions that can lead to feelings of disorientation and confusion. It is the latter—the confusion we feel, for instance, when we hear conflicting health advice in the media—of which we must beware. In confusion, we as individuals are prey to paranoia, hysteria and manipulation by special interest groups, and we may inadvertently cede away our decision-making to others.

As my paranoid musings in bed suggest, our growing awareness of the risks around us—many of which have always been there—can make people feel vulnerable. When we hear of a new exotic risk, we may react too strongly, failing to compare the severity of this risk with other risks in our lives. Thus, after an accidental death in a subway escalator, public outrage demands multi-million dollar safeguards. However, other urban problems, such as lead poisoning in children, remain far more destructive but do not awaken a universal sense of outrage. The fusillade of risk statistics and information we read daily in newspapers and magazines, and hear on the radio and television, can lead to feelings of impotence: ordinary citizens may be tempted to throw up their hands and dismiss much of modern science. Some may decide to embrace a different belief system other than modern science that somehow appears more humane to them.

Chasing zero risk has risks of its own

On a radio interview programme recently, one caller asked me if she could use risk analysis to evaluate whether or not she should marry her boyfriend. I admit to being taken aback by this apparently sincere question. Ultimately, probability theory and the fruits of risk analysis are only tools. Unto themselves, they cannot lead us to some absolute, right answer in any matter, be it how to choose in love, or whether to build a highway or to smoke cigarettes. It is up to us as individuals, and

collectively as a culture, to make the judgements about what we will and will not tolerate. Thinking in terms of risk and probability simply gives us more information with which to make better decisions that will bring us closer to what we ultimately desire. As experts we must be careful not to ask citizens to cede away the important decisions they face. Nor must we as individuals give away our right to make decisions. Should I tell that woman on the radio programme how to love? Should a healthcare provider make crucial decisions without the input of the patient? Certainly not. Excluding the individual from the decision-making process can only lead to alienation, a lack of ownership and more lawsuits when things go wrong.

Nor must we always take the safest path. We may choose to do risky things because the possible benefits are high. Manned space flight, for instance, holds great risks in terms of lives and money lost, but these risks may be deemed worthwhile. The exhilaration of downhill skiing for an individual may offset the risk of breaking a limb. Chasing zero risk has risks of its own. Instead, we must embrace the idea of relative risk, the notion that everything contains some element of risk and thus we must choose our paths judiciously. If we fail to understand where these innovations in risk and probability occur, then we may become slaves to them as opposed to using them as powerful tools. Thus, we might not take advantage of the remarkable revolution that Blaise Pascal started three centuries ago.



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