Technology Assessment from the Stance of a Medieval Historian

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ON OCTOBER 13, 1972, the American federal government established in Washington an Office of Technology Assessment to advise Congress on legislative problems related to new technology and its probable impact. This act reflects an ambivalence toward engineering innovation that has been rare during the last thousand years in the Occidental culture of which we are part. Both pagan and Christian antiquity, of course, had been dubious about technology. St. Augustine, the most penetrating mind of a groping age, expressed amazement at the ingenuity and variety of the arts, yet feared that the good coming from them may be counterbalanced by the evil of "so many poisons, weapons and military machines" in addition to superfluities and vanities.[1] The Latin Middle Ages, by contrast, developed an almost entirely affirmative view of technological improvement. This new attitude is clearly detectable in the early ninth century, and by 1450 engineering advance had become explicitly connected with the virtues: it was integral to the ethos of the West.[2]

People are organized into cultures by the basic presuppositions—often unverbalized—that they share: their axioms. They put their intelligence, energy, and money into what they corporately consider good. The results are as varied as the majestic pyramids of pharaonic Egypt, the sadistic games of the arenas of the Roman West, and the family-centering, but globally focused, television sets of the contemporary industrialized world. Medieval Europe came to believe that technological progress was part of God's will for man. The result was an increasing thrust of invention that has been extrapolated, without interruption or down-curve, into our present society.

This is a presidential address delivered by Mr. White at the annual meeting of the American Historical Association, San Francisco, December 28, 1973.

[1] *De civitate Dei* 22.24, in *Corpus christianorum, series latina,* 48 (Turnholt, 1955): 848–49.

[2] See Lynn White, jr., "The Iconography of *Temperantia* and the Virtuousness of Technology," in T. K. Rabb and J. E. Seigel, eds., *Action and Conviction in Early Modern Europe: Essays in Memory of E. H. Harbison* (Princeton, 1969), 197–219; and White, "Cultural Climates and Technological Advance in the Middle Ages," *Viator,* 2 (1971): 171–201.

Never was the sense of the virtuousness of technology more vivid than in nineteenth-century America. In 1853 an English mission exploring the sources of industrial success on this side of the Atlantic concluded, in awed tones, that "the real secret of American productivity is that American society is imbued through and through with the desirability, the rightness, the morality of production. Men serve God in America, in all seriousness and sincerity, through striving for economic efficiency."[3] Clearly this Victorian investigative team did not know that they were observing an attitude that had been held by the common medieval and puritan ancestors both of themselves and of the renegade colonists: in England it was already in decay. In New England, however, it survived until toward the end of the century, when its demise was signaled in Henry Adams's dichotomy of Dynamo and Virgin, a tragic vision of reality most curiously presented against the backdrop of a totally misunderstood Middle Ages.[4]

Today the medieval axiom of the rightness of technological progress has been challenged in the entire Western world, and not merely by mystics and eccentrics of the Blake and Thoreau ilk. To the secular among us it seems quaint; to the religious it is blasphemy. The most extreme repudiation of it is that by Jacques Ellul, a French Calvinist professor at Bordeaux, to whom "Technology" appears to be the new name for Antichrist, a demonic force that is completely out of hand.[5] Few will go so far; yet among us, few likewise still share the old confidence that all problems produced by changing engineering will be solved automatically by remedial forms of technology, quite without the intrusion of public policy based on ethical and esthetic sensibility. Hence the establishment by Congress of the Office of Technology Assessment.

We must have assessment of technology: our national crises of energy, exhaustion of natural resources, and pollution of air, water, and soil interlock with global crises of armaments, population, and food. The real question is: Do we know how to assess a proposed technological change, whether it be a new invention or a new canal across Central America?

Technology assessment today is a discipline largely concerned with weapons systems, industrial production, power networks, traffic patterns, marketing problems, and large engineering projects. The systems analysis that is its method is based almost entirely on costs-benefits calculations that are narrowly construed because they are designed to answer military and business questions formulated within a rather limited range set by those commissioning the studies. Their failure to ask about wider social and other costs and benefits has led to unfortunate effects that impinge increas-

[3] Quoted by Charles L. Sanford, "The Intellectual Origins and New-Worldliness of American Industry," *Journal of Economic History,* 18 (1958): 16; see also page 14 for Patrick Tracy Jackson's dictum that "the village steeple is an unfailing companion of the waterwheel."

[4] Lynn White, jr., "Dynamo and Virgin Reconsidered," *American Scholar,* 27 (1958): 183–94; reprinted in White, *Machina ex Deo: Essays in the Dynamism of Western Culture* (Cambridge, Mass., 1968), 57–73.

[5] Jacques Ellul, *The Technological Society,* tr. J. Wilkinson (New York, 1964).

ingly on the lives of millions, with resulting popular backlash against engineers and scientists, soldiers and business leaders.

Some of the most perceptive systems analysts are pondering today how to incorporate into their procedures for decision the so-called fragile or nonquantifiable values to supplement and rectify their traditional quantifications. Unhappy clashes with aroused groups of ecologists have proved that when a dam is being proposed, kingfishers may have as much political clout as kilowatts. How do you apply cost-benefit analysis to kingfishers? Systems analysts are caught in Descartes's dualism between the measurable *res extensa* and the incommensurable *res cogitans*, but they lack his pineal gland to connect what he thought were two sorts of reality. In the long run the entire Cartesian assumption must be abandoned for recognition that quantity is only one of the qualities and that all decisions, including the quantitative, are inherently qualitative. That such a statement to some ears has an ominously Aristotelian ring does not automatically refute it.

There is a second present defect in the art of technology assessment: the lack of a sense of depth in time; this may be called the Hudson Institute syndrome. It is understandable not only because most systems analysts are trained either in engineering or in the social sciences that normally take a flat contemporary view of phenomena, but also because the concrete problems set before systems analysts for solution look toward future action and discourage probing the genesis of things. Since history deals with nonrepetitive events, historians cannot help in specific ways to answer questions concerning assessment of technology in our time. I believe, however, that contemporary technology assessment will become sophisticated and more successful only if those who practice it are made aware of the complexity and ramifications of the effects of technological changes in the past. History can offer no solutions, but it may help to guide an acute mind toward kinds of questions that in the present state of systems analysis tend to be overlooked. Above all it may illuminate the limitations as well as the possibilities of assessing technology.

To show what I mean, let me present a rapid and necessarily superficial review of a few Western medieval innovations and their impacts. To what extent could a prescient medieval futurologist have foreseen what was going to happen?[6]

SOMETIME BETWEEN 1150 and 1167 alcohol, or, more exactly, brandy, was first distilled from wine as a pharmaceutical at Salerno, the site of Europe's most

[6] There appears to be no study of the development of the more modern social-psychological kinds of insight, as contrasted with the legal-political Greco-Roman way of analyzing situations and trends. That seeds of the new method were sprouting in the later thirteenth century is shown by Brian Tierney, *Medieval Poor Law: A Sketch of Canonical Theory and Its Application in England* (Berkeley, 1959), 44–67. Canonists at that time began shifting the focus of discussions of charity from its effect upon the spiritual well-being of the donor to its impact upon the recipient.

famous medical school.[7] Drunkenness, of course, had produced moral and social problems ever since Noah took shore leave (Gen. 9:21–27), and it is not likely that anyone in the later twelfth century could have thought that the new medicine would amplify a traditional vice. The considerable medieval literature on *aqua ardens* or *aqua vitae* stresses the beneficial effect of alcohol for facial tic, chronic headache, stomach trouble, falling or graying hair, worms, epilepsy, cancer, sterility, sciatica, arthritis, and bad breath. In general, it was good for people who, in terms of the humoral physiology of that age, were considered to have a "cold" temperament. Then in the midst of such medical advice, one treatise lets down its guard: "Brandy when drunk makes a man happy and sociable":[8] in other words, this is the "fun" medicine.

Especially in Northern Europe the winters were chilly enough to make anyone believe that he was of a "cold" complexion and that such a medicament was essential to his health. Apothecaries were making it in ever more considerable quantities, and during the fifteenth century, when it began to be produced from a beer mash as well as from wine, it became quite cheap. Drunkenness and consequent public disorder increased alarmingly: for example, at Frankfurt am Main decrees trying to cope with the problem—but obviously in vain—were issued in 1361, 1391, 1433, 1456, and 1487.[9]

India and Sunnite (as distinct from parts of Shiite) Islam arrived at a negative assessment of intoxicants long before alcohol was distilled. In 1919 the United States reached the same conclusion, but so many socially evil side effects of that decision emerged that by 1933 the consensus was reversed. Alcohol remains fun for many, and a disaster for many. As the annual meetings of this Association demonstrate, it adds considerably to conviviality and perhaps even to the flow of ideas. Statistics, however, indicating that half the traffic deaths in this country are connected with either drunken drivers or drunken pedestrians make one wonder about the beneficence of the Salernitan gift to mankind. A study group eight centuries ago, equipped with entire foresight, would have failed at an assessment of alcohol as today we fail.

In our own generation some of the most successful technology assessments have dealt with weapons. How would similar efforts have fared in the Middle Ages, or how did they?

In the later eleventh century the West developed a new and more power-

[7] E. O. von Lippmann, "Zur Geschichte des Alkohols," *Chemiker-Zeitung*, 44 (1920): 625. Despite the efforts of Mohammed Yahia Haschmi to show the contrary, there is no firm evidence that alcohol was discovered in Islam earlier than in Europe: *aqua vitae* was given its pseudo-Arabic name by Paracelsus. "Sur l'histoire de l'alcool," *Actes du XII^e Congrès international de l'histoire des sciences, 1968*, 3a (1971): 69–72.

[8] "Item gebrant win gedruncken machet den menschen frolich und wohl gemüt." Gundolf Keil, "Der deutsche Branntweintraktat des Mittelalters," *Centaurus*, 7 (1960): 84.

[9] Robert J. Forbes, *Short History of the Art of Distillation* (Leiden, 1948), 90–91.

ful form of crossbow, presumably made possible by a firmer trigger.[10] Anna Comnena tells us that at the time of the First Crusade the Byzantines regarded it as a Frankish novelty;[11] eventually it spread as far as South India, where it was known as the *parangi,* or "Frankish" bow.[12] The wounds from its bolts were terrible, and in 1139, at the Second Lateran Council, Innocent II banned it on moral grounds, except for use against infidels.[13] The prohibition was unenforceable: in the heat of warfare, every foe seemed at least a crypto-infidel. The nonquantifiable value of compassion was indeed fragile in the face of the crossbow's measurable ability to shoot further and hit harder than any other portable missile thrower before the English longbow appeared in the later thirteenth century. As between clear negative and affirmative assessments of the crossbow, the latter won out.

Edward I of England learned to respect the longbow in the hands of the Southern Welsh, both his foes and his allies. He and his staff appraised it correctly: using it in Wales and Scotland, he worked out new tactics and combinations of forces that made the English army almost invincible until toward the end of the Hundred Years' War.[14] In the hands of a skilled archer, cloth-yard shafts of great striking force could be launched several times more rapidly than an equally powerful crossbow could be reloaded and shot. The supply of archers remained sufficient for nearly a century before it began to dry up because of a change in the recreational patterns of English commoners. In 1365 Edward III—a ruler of great military acumen—commanded all sheriffs to suppress bowling, quoits, handball, football, club ball, hockey, cockfighting, "and other vain games of no value," and to see to it that on Sundays and holidays Englishmen of the lower orders should practice with bows and arrows. In 1388 tennis and dice were added to the list of banned sports, and similar measures were enacted into the sixteenth century.[15] Nevertheless, the long decline of English archery continued: in 1549 Bishop Hugh Latimer thundered that "we have taken up whoring in towns instead of shooting in the fields."[16] When in 1595 the longbow was officially discarded by Elizabeth's army in favor of the musket, it was still technically the superior weapon.[17] The musket, how-

[10] The earliest picture of it that I have found—Christian Spanish, dated 1086—stresses the trigger; see Pedro de Palol and Max Hirmer, *Early Medieval Art in Spain* (New York [1967]), 58 and pl. XIV.

[11] Anna Comnena, *Alexiad* 10.8.6, ed. B. Leib (Paris, 1945), 2: 217–18.

[12] J. Hornell, "South Indian Blow-guns, Boomerangs and Crossbows," *Journal of the Royal Anthropological Institute of Great Britain and Ireland,* 54 (1924): 344–45.

[13] "Artem autem illam mortiferam et Deo odibilem ballistariorum et sagittariorum adversus Christianos et Catholicos exerceri de cetero sub anathemate prohibemus." J. D. Mansi, *Sacrorum conciliorum nova et amplissima collectio* (Venice, 1776), 21: 533.

[14] John E. Morris, *The Welsh Wars of Edward I* (Oxford, 1901), 99–104.

[15] Austin Lane Poole, "Recreations," in A. L. Poole, ed., *Medieval England* (new ed.; Oxford, 1958), 625.

[16] Hugh Latimer, *Sermons,* ed. G. E. Corrie (Cambridge, 1844), 197.

[17] See Thomas Esper, "The Replacement of the Longbow by Firearms in the English Army," *Technology and Culture,* 6 (1965): 393.

ever, was reasonably effective in the hands of less well-trained soldiers, and that fact was decisive.

Could Edward I have foreseen that Englishmen might not always shoot at the butts, and could he have taken successful measures to prevent the decay of archery before it proved irreversible? To tell the truth, we still do not know with any certainty the reasons for that decay. Archery doubtless prospered best in hamlets so small that they lacked a tavern or enough inhabitants for many group games. A relevant factor, long at work by Edward I's time, was the gradual shift, especially in the more fertile areas, from the ox to the swifter horse as the ordinary beast for plowing. This reduced by one-half the time spent going and coming between stable and plowland and encouraged peasants to abandon hamlets, while working the same fields, and to agglomerate into larger villages where life was more lively.[18] Moreover, the shrinkage of population during the second half of the fourteenth century led to abandonment to pasture of much cultivated land of marginal productivity and small settlements: the now scarcer peasant labor was concentrated on the more profitable soils, and thus in larger villages.[19] It is doubtful that any number of royal decrees could have perpetuated archery indefinitely in the face of the new tempo and variety of popular life in late medieval England. In any event, three centuries after Edward, Elizabeth was forced by the dearth of skilled personnel to resort to the technically inferior musket.

What about medieval artillery? The torsion artillery of Hellenistic and Roman times was often unsatisfactory because the skeins of hair or sinews powering the machines stretched in wet weather and lost their resilience. During the later Carolingian period the West received from Islam—or else by way of Islam—a new sort of stone thrower consisting of a horizontally pivoted beam with a sling at the shooting end and ropes at the other that were pulled simultaneously by a gang of men.[20] This was an artillery for all seasons, and it probably replaced the classical types speedily. The pattern remained unchanged until toward 1200, when some engineer, a European it would seem,[21] realized that labor could be saved, size increased, and accuracy of aim improved if a great counterweight were substituted for the gang of men who pulled the ropes. Such machines, called trebuchets, developed amazing capacities in the early thirteenth century. The counterweight and firing arm being uniform, properly calibrated stone balls of equal weight would hit the same spot on a fortification at each shot.[22] A great trebuchet designed by Bishop Durand of Albi in 1244 to besiege the

[18] See Lynn White, jr., *Medieval Technology and Social Change* (Oxford, 1962), 67–68.

[19] Maurice W. Beresford finds little evidence of immediate and catastrophic abandonment of settlements following the epidemics. *The Lost Villages of England* (London, 1954), especially 158–66.

[20] Donald R. Hill, "Trebuchets," *Viator*, 4 (1973): 99–114.

[21] Muslims often called the largest trebuchets "Frankish machines" *(manjaniq faranjī)*.

[22] Such trebuchet balls were being produced according to engineers' specifications in England by 1244; see John Harvey, *English Mediaeval Architects* (London, 1954), 111.

Cathar stronghold of Montségur threw a forty-kilogram missile at its walls at twenty-minute intervals, day and night, for weeks and proved to be the key, opening defenses that had seemed impregnable.[23]

Had an Office of Technology Assessment been asked to present a report on gunpowder artillery when it first appeared at Florence in 1326,[24] the measuring rod of effectiveness would have been the trebuchet. The earliest cannon were crude, cumbersome, and inefficient. They were costly to make and costly to supply with their chemical fuel. They could not be aimed with any great exactness; they were slow to load and to fire; they could rarely hit the same spot on a fortification twice because of irregular composition and combustion of the powder. The shaking of gunpowder during transport made the lighter charcoal particles rise to the top, with the result that early gunpowder had to be carefully remixed just before it was used: a perilous process during battle. We have no evidence that corned gunpowder—designed to prevent this difficulty and also to assure even combustion by introducing small air spaces—was known before 1429.[25] Any rational technology assessment of the cannon in 1326 or for a hundred years later would have concluded: "Stick to the trebuchet."

Yet Europe did not stick to the trebuchet: by the end of the century trebuchets had been practically discarded.[26] Why? Probably because of the cannon's splendid roar and flash, and also because the extravagance of it made it a status symbol. The greater cost-benefit efficiency of the trebuchet as a weapon succumbed to the nonquantifiable values of vanity and political visibility. It was decades after the eclipse of the trebuchet that the prolonged labors of guncasters, industrial chemists, and gunners finally transformed cannon into an artillery as effective as the kind it had replaced. One doubts that any futurologist of 1326, contemplating those cannon at Florence, could have anticipated so complex a course for the new weapon.

There is at least one instance of the social impact of a medieval invention that might easily have been assessed intelligently, only to have the prognosis overturned by later events. As Edward Rosen of the City University of New York has shown, eyeglasses were invented by a man who was living in the Lucca-Pisa area in the 1280s.[27] They were a boon to the presbyopic, and

[23] Fernand Niel, *Montségur: le site, son histoire* (Grenoble, 1962), 222.

[24] Carlo M. Cipolla reproduces the Florentine document of February 11, 1326, referring to the purchase of "pillas seu palloctas ferreas et canones de mettallo." *Guns and Sails in the Early Phase of European Expansion, 1400–1700* (London, 1965), 32 pl. An English manuscript of 1327 shows a picture of a cannon; thereafter the evidence is massive.

[25] See A. O. von Essenwein, *Quellen zur Geschichte der Feuerwaffen* (Leipzig, 1872), 25.

[26] Philippe Contamine concludes that the expansion of French royal artillery was particularly rapid in 1395–1400; he cites Christine de Pisan's list of matériel needed for a great siege as including 8 trebuchets of 2 models, but also 128 cannon supplied with 30,000 pounds of powder; for the projected siege of Calais at just that time (1406) the French army procured at least 20,000 pounds of powder. *Guerre, état et société à la fin du moyen âge: Études sur les armées des rois de France, 1337–1494* (Paris, 1972), 229 n.115, 665–66.

[27] Edward Rosen, "The Invention of Eyeglasses," *Journal of the History of Medicine and Allied Sciences,* 11 (1956): 13–46, 182–218.

their use spread rapidly. Any contemporary, if he had thought about it, could have seen that this would enable aging men in teaching, the book trade, law, bureaucracy, banking, commerce—indeed, in any occupation that demanded frequent reading—to keep actively at work longer than otherwise would have been possible. Eyeglasses thus would slow the promotion of younger men, lead to discontent among them, and produce a generation gap. Indeed, *a priori,* the common use of spectacles certainly tended to produce such a slowing of youthful careers. However, the first half of the fourteenth century was a period of such turmoil that life expectancies seem to have decreased even before the catastrophe of the Black Death.[28] While young and old perished alike, the higher general incidence of death led to increased velocity in promotions and thus masked the reverse effects of the introduction of eyeglasses.

There are some technological developments that seem initially so modest, and that grow so quietly, that even in our own day no one would wonder about their impact until long after the effects were irreversible. Leroy J. Dresbeck of Western Washington State College has recently clarified such an instance in his study of the chimney flue and mantled fireplace.[29]

For heating, the Romans used braziers and hypocausts (radiant heating). Braziers burned charcoal and were thus costly to operate; moreover, in a room tightly closed against the weather they were dangerous: the Emperor Julian, wintering in Paris, was once nearly killed by carbon monoxide from a brazier.[30] Hypocausts were inflexible and wasteful of fuel because they heated the entire mass of the masonry of floors or walls. In the variable climate of Northern Europe, and especially in winter, they would not do. During the early Middle Ages, whether in hovel or royal hall, people centered their lives around a fireplace in the middle of a room with a high, louvered roof to carry out the smoke. Unfortunately it carried out much of the heat as well.

By the ninth century the central fireplace was occasionally moved to a corner of the room and was covered by a hood or mantle to catch the smoke and take it out through a hole, or even up a chimney. Experimentation with the design of chimney stacks led to the discovery that a draft of air can be brought down the flue to reverse itself and draw off the smoke while leaving much of the heat to be radiated into the room. Moreover, replacement of louvers by chimneys meant that fireplaces could be located on any level of a multistoried building and not merely under a roof directly beneath the sky. In the eleventh century chimneys and mantled

[28] For a learned summary, see Josiah C. Russell, "Effects of Pestilence and Plague, 1315–1385," *Comparative Studies in Society and History,* 8 (1966): 464–73. There is some evidence that mature men were especially vulnerable to the plague.

[29] L. J. Dresbeck, "The Chimney and Fireplace: A Study in Technological Development Primarily in England During the Middle Ages" (Ph.D. dissertation, University of California, Los Angeles, 1971); summary in "The Chimney and Social Change in Medieval England," *Albion,* 3 (1971): 21–32.

[30] *The Works of the Emperor Julian,* tr. W. C. Wright (London, 1913), 2: 430–33.

fireplaces became common in the dwellings of the great. By the end of the twelfth, even the poor were enjoying them.

Much more than simple comfort was involved. In the days of the old central fireplace, to keep warm in Northern Europe everyone from lord and lady to humblest servant lived and ate together in the great hall, and slept there, too, normally in curtained compartments. Society was hierarchical, but the strata knew each other intimately. With the new flexibility of heating made possible by chimney and mantled fireplace, privacy could be implemented. Lord and lady increasingly ate, lived, and slept in withdrawing rooms. As affluence increased, noble residences were redesigned so that rank after rank of the social structure could enjoy the new sense of individuation in its life style. To Dresbeck's remark that the chimney may have affected the art of love more than the troubadors did,[31] one may add that it may likewise have fostered the individualism of the later Middle Ages more than all the humanists. Yet a high social price was paid for the new ideal of the idiosyncratic person. As communication between classes decreased, class consciousness and snobbery grew. By the 1370s William Langland was assessing the chimney bitterly:

> Woe is in the hall each day in the week.
> There the lord and lady like not to sit.
> Now every rich man eats by himself
> In a private parlor to be rid of poor men,
> Or in a chamber with a chimney,
> And leaves the great hall.[32]

The chimney is as important as any other single factor in the shift from medieval to modern Occidental attitudes, and not all of this process was good. I doubt, however, whether anyone much earlier than Langland could have assessed properly its less desirable effects, and by that time the process could not be turned back.

Indeed, technology assessment becomes an enterprise of almost terrifying immediacy when we realize that our most intimate psychic structure may at times be influenced by seemingly minor external innovations. The modern American family is often a paidocracy, child centered to a degree unknown elsewhere; yet our pattern is the completion of one long developing in Europe. Philippe Ariès's *Centuries of Childhood*[33] is a blunder-

31 Dresbeck, "The Chimney and Fireplace," 207.

32 This passage is found only in the B text: William Langland, *The Vision of Piers the Plowman: The "Crowley" Text; or Text B,* ed. Walter W. Skeat, Early English Text Society, 38 (London, 1869), passus X, lines 93–98.

33 Philippe Ariès, *Centuries of Childhood: A Social History of Family Life,* tr. R. Baldick (New York, 1962). The French original has a more exact title: *L'enfant et la vie familiale sous l'ancien régime* (Paris, 1960). For an acute analysis of Ariès's not-always-coherent thesis, see David Hunt, *Parents and Children in History: The Psychology of Family Life in Early Modern France* (New York, 1970), 27–51. Urban T. Holmes, "Medieval Children," *Journal of Social History,* 2 (1968): 164–72, warns that Ariès's picture of the plight of the medieval child is too grim; however, Richard C. Trexler, "Infanticide in Florence: New Sources and First Results," *History of Childhood Quarterly,* 1 (1973): 98–116, indicates a remarkable amount of deliberate infanticide in fifteenth-century Florence, particularly directed against girl infants.

ing and often perverse book that nevertheless establishes that in the Middle Ages no one paid much attention to children before about the age of seven, when they were admitted to the world of grown-ups. He believes that it was not until the later sixteenth or the seventeenth century that our culture discovered the "sweetness, simplicity and drollery" of small children, began to enjoy and coddle them, to accept them on their own terms, and to dress them in special clothes that were not simply small versions of adult attire. I myself would push the beginnings of the change somewhat earlier, but must recognize that in the early fifteenth century a family like the Pastons paid amazingly little attention to their younger offspring.[34]

It is assumed that this indifference was an effort to defend adult emotions against the grim fact of infant mortality. No one could afford to invest great emotional capital in a child whose chances of survival were 50 per cent or less. Not until five to seven years had proved a certain durability could one risk great affection or interest. I believe that this hypothesis makes sense, but it leaves unexplained the reasons for the presumed improvement in child survival that at last led parents to venture lavishing affection upon the very young.

I see no clues in sanitation, diet, or medicine.[35] Explanation must be found elsewhere. Partly because their bodies are so small, little people are peculiarly vulnerable to cold and resulting pulmonary infections. We have already noted that in the later Middle Ages houses of all classes were better heated than before, and the increased glazing of windows helped to retain the heat. But the snugness of clothing was also much improved. The first functional buttons appeared in central Germany in the 1230s,[36] and by the fourteenth century they were revolutionizing costume design. In the dress of modern American and European children knit textiles are basic. The first evidence of a knit body garment (as distinct from a few specimens of socks, gloves, and so forth)[37] is on an altarpiece from Buxtehude near Hamburg painted in the last decade of the fourteenth century. It depicts the

[34] See Ann S. Haskell, "The Paston Women on Marriage in Fifteenth-Century England," *Viator,* 4 (1973): 469.

[35] That the first two European treatises exclusively devoted to distinguishing the medical problems of children from those of adults—Paolo Bagellardi, *Libellus de infantium aegritudinibus* (Padua, 1472) and Bartholomaeus Metlinger, *Ein Regiment der jungen Kinder* (Augsburg, 1473)—appeared only a year apart both north and south of the Alps, assuredly reflects the rather sudden development of a new attitude toward small children, but the practical medical effect of such treatises, as distinct from the effect of the new attitude, on infant mortality is in doubt.

[36] Some buttons were used in antiquity for ornament, but apparently not for warmth. The first functional buttons are shown ca. 1235 on the "Adamspforte" of Bamberg Cathedral and in 1239 on a relief at Bassenheim; see Erwin Panofsky, *Deutsche Plastik des 11. bis 13. Jahrhundert* (Munich, 1924), plate 24; Hermann Schnitzler, "Ein unbekanntes Reiterrelief aus dem Kreise des Naumburger Meisters," *Zeitschrift des Deutschen Vereins für Kunstwissenschaft,* 2 (1935): 413, fig. 13.

[37] A. Latour is dubious about claims that certain finds in Coptic graves of the fifth to seventh centuries are in fact knitted; he holds that the first firm evidence of knitting is late medieval, notably a pair of knit gloves that belonged to Pope Clement V (d. 1314). "The Stocking," *CIBA Review,* no. 106 (1954): 3800.

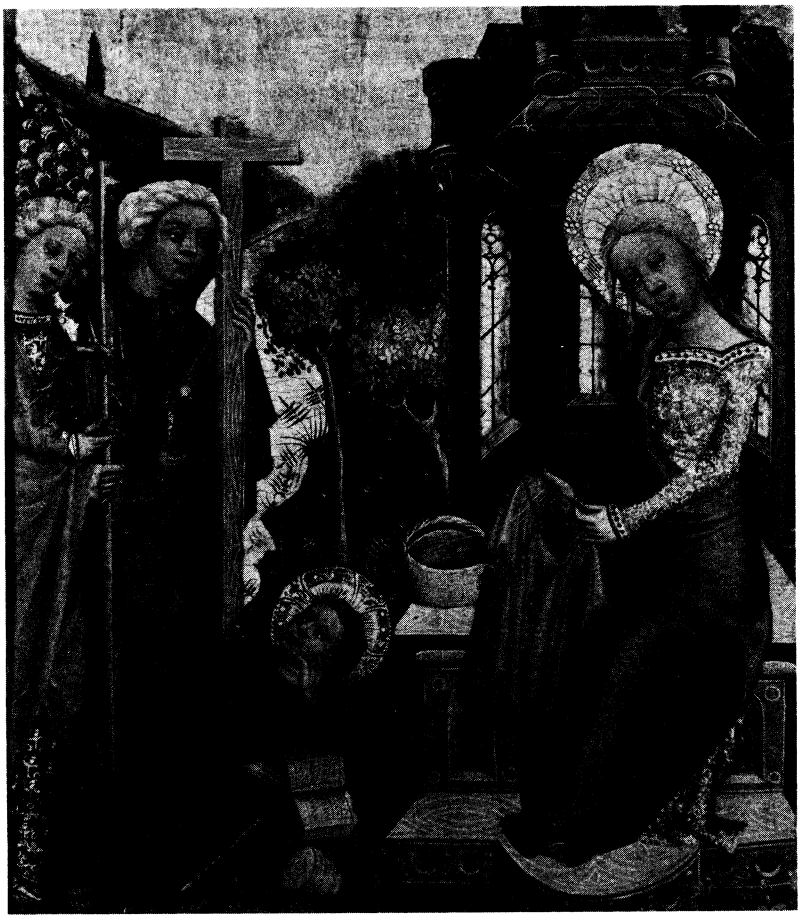

Fig. 1. Panel of the Buxtehude Altarpiece, anonymous, ca. 1395, in the Kunsthalle, Hamburg. (See n. 38.)

Virgin Mary knitting a shirt on four needles for the Christ child[38] (see fig. 1). It is a safe surmise that the development of knitting, along with functional buttons and heating devices, helped to keep more little children alive, and thus played a large part in fostering modern attitudes toward them. Late medieval mothers and grandmothers with clacking needles undoubtedly assessed knitting correctly as regards infant comfort and health, but that in the long run a new notion of relationships within the family would thereby be encouraged could scarcely have been foreseen.

[38] Hamburg, Kunsthalle. On the date and context see Wilhelm Worringer, *Die Anfänge der Tafelmalerei* (Leipzig, 1924), 193–94, fig. 59, and Alfred Stange, *Deutsche Malerei der Gotik* (Nedeln, 1934), 2: 145–50, figs. 178, 181. The knitted shirt is the seamless garment that Christ wore at his crucifixion; legend says that his mother made it and that it grew as he did. The precocious infant turns from reading scriptural prophecy to meditate upon the vision of two angels holding instruments of his passion. A whipping top lies abandoned at his side. We lack an adequate history of toys: such a study would tell us much about adult attitudes toward children.

How far into the future can even the sharpest eye look? Let me sketch another sequence that starts with textiles but ramifies curiously.

With the old toplike spindle the production of thread was slow and laborious. Especially after the horizontal heddle-treadle loom displaced the vertical loom in the eleventh to twelfth centuries,[39] in the production of simple unpatterned cloth one weaver could use the product of many spinners. The first known spinning wheel appears in a Chinese painting of about 1035.[40] During the thirteenth century[41] this invention reached Europe. We may be sure that the people making and selling textiles recognized at once—although none seems to have recorded his views—that the new instrument, by speeding yarn production, considerably reduced the labor component of the final cost of plain cloth. In the very competitive pan-European textile market of that age, this meant a lowering of prices and consequent increase of consumption. Linen was particularly affected, both because it was normally unpatterned and because it was seldom dyed, only bleached by exposure to sunlight. A good merchandiser of the late thirteenth century might have foreseen what in fact happened in the fourteenth century: an immense increase in the use of linen shirts, underwear, bed linen, towels, and even vast coifs of starched and folded linen decking the heads of fashionable ladies.

Contemporary technology assessment of the spinning wheel might reasonably have probed even further. Increased use of linen meant more linen rags, and probably cheaper. Linen rags were the best material for making paper. This meant that the burgeoning new paper industry could expand production, lower prices, and increase consumption.

I greatly doubt that even the keenest systems analyst, looking at the potential of the new spinning wheel in the thirteenth century—or perhaps for three generations thereafter—could have gone further than this. Yet with the wisdom of hindsight we can perceive that the second impact of the spinning wheel was not on the textile industry but on the book business.

To produce a large Bible took the skins of between two and three hundred sheep or calves. The preparation of parchment and vellum was arduous and the finished product expensive. By a happy chance we know that in 1280 at Bologna paper was already six times cheaper than parchment.[42] Although I have no proof, it is probable that the relative cost of paper continued to decline. Except for deluxe volumes, paper was increasingly

[39] The earliest European evidence of the horizontal loom appears in the Talmudic commentary of Rabbi Rashi (d. 1105), written in Northern France; see Eleanora Carus-Wilson, "Haberget: A Medieval Textile Conundrum," *Medieval Archaeology,* 13 (1969 [1971]): 165. Rashi indicates that it is used by professional male weavers, in contrast to the old vertical loom used by women weavers.

[40] Joseph Needham, *Science and Civilization in China,* vol. 4, pt. 2 (Cambridge, Eng., 1965): 758–59.

[41] For the recent literature, see Walter Endrei, "Changements dans la productivité lainière au moyen âge," *Annales: économies, sociétés, civilisations,* 26 (1971): 1291–99.

[42] C. M. Briquet, *Les filigranes* (2d ed.; Leipzig, 1923), 2: 317.

used in making manuscripts. This meant that the wages of the scribe became by far the greatest cost in manufacturing a book. There was every incentive to experiment with mechanical means of writing and, when a method was found, to make the considerable capital investment needed to operate it. This was Gutenberg's accomplishment. Its presupposition was the spinning wheel.

Elizabeth Eisenstein of the American University has recently revivified in so salutary a way discussion of printing's impact upon our culture[43] that nothing need be said here. While conclusions may differ about specifics, there is agreement that the Western world was deeply shaken by the printed book. It is curious, but consonant with the axiom of the goodness of technological change, that among contemporary Europeans—save for a very few snobbish bibliophiles—enthusiasm for printing was complete.

Not so in Islam: here the technology assessment of printing was so negative that it lasted for centuries. The techniques were easily available: Maronite, Greek, Armenian, and Jewish subjects of Muslim rulers were operating presses for their own purposes long before there was any printing in Turkish, Persian, or Arabic.[44] Many parts of Islam were sophisticated and creative, as the monuments of sixteenth-century Istanbul or seventeenth-century Isfahan amply demonstrate. There was no general allergy to borrowings from Europe, as the adoption of gunpowder artillery shows.[45] The avoidance of the printing press appears to have been deliberate and selective. So far as I can discover, no one has yet explored what Muslims said to each other about printing and their opposition to it. I personally suspect that the leaders of Islamic society felt—perhaps subliminally—that cheap books would eventually destroy the elitist world that they valued. If so, they were correct, as the later history of the West proves.

THIS LITTLE CLUSTER of case studies that I have offered was selected not at random, but rather to show different levels of complexity, or different kinds of relationships, that may be found in the assessment of a new technology. My thesis is that technology assessment, if it is not to be dangerously misleading, must be based as much, if not more, on careful discussion of the imponderables in a total situation as upon the measurable elements. Systems analysis must become cultural analysis, and in this historians may be helpful.

[43] Among her several articles, see especially Elizabeth L. Eisenstein, "The Advent of Printing and the Problem of the Renaissance," *Past and Present,* no. 45 (1969): 19–89, and no. 52 (1971): 135–44; "The Advent of Printing in Current Historical Literature," *AHR,* 75 (1969–70): 727–43; and "L'avènement de l'imprimerie et la Réforme," *Annales: économies, sociétés, civilisations,* 26 (1971): 1355–82.

[44] For the beginnings of Hebrew and Syriac printing under Islamic rule, see Jean Muller and Ernst Roth, *Aussereuropäische Druckereien im 16. Jahrhundert: Bibliographie der Drucke* (Baden-Baden, 1969), 53, 57–60, 63, 65–67. Armenian and Greek printing in the Near East began in the seventeenth century.

[45] See the remarkable study by David Ayalon, *Gunpowder and Firearms in the Mamluke Kingdom: A Challenge to a Medieval Society* (London, 1956).