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The Factors of Technological and Industrial Progress in the Later Middle Ages

† E. Ashtor
Hebrew University of Jerusalem

The great progress made by technology and industrial production in the Middle Ages has attracted the attention of many distinguished historians. It may now be timely to elaborate the factors which made this progress possible. But because social conditions in that era were very different from those of today, one cannot apply the theories developed by modern economists and other interpretations must be sought.

Modern economists have distinguished between invention and innovation, the former referring to novelties in technology and the latter to new elements in economic organisation.[1] The economic historian who deals with technological progress in the Middle Ages soon becomes aware of the fact that the distinction between the role of the inventor and the entrepreneur is often blurred. Even when considering the range of the inventions, he cannot be as exact as the historian of a modern economy. In order to draw a clear picture of industrial progress, he cannot isolate it from the general advance of technology. The same is true for chronological and geographical delimitation. The great progress made in industrial production in the later Middle Ages

[1] See V. Ruttan, *Usher and Schumpeter on invention, innovation and technological change*, in *The economics of technological change*, ed. N. Rosenberg (Middlesex, 1971), p. 74, 79.

lends itself more to historical and sociological interpretation because of the relative wealth of sources. However one cannot ignore developments in earlier periods, as the picture would be inaccurate. In order to put into perspective the great progress made by European industries at the end of the Middle Ages, it should be compared with the stagnation and industrial decline in the neighbouring Near Eastern countries.

I

One of the factors which was considered to have promoted technological progress in the Middle Ages is Western Christianity. This argument was put forward by Lynn White who claimed that there is no evidence to support the view that social conditions (such as the scarcity of labour) were important for technological advance in the later Middle Ages.[2] To understand the factors which promoted technological progress in medieval Europe, one should consider the different ideas about labour amongst Western (Latin) Christians, Greek-Orthodox Christians and Moslems. From the beginning Christianity showed a different attitude from the Greeks and Romans towards labour, and placed much greater value on it. But Western Christianity was distinguished in particular by its voluntarist tradition. Physical work acquired a spiritual value, akin to worship. Mastering nature was close to collaboration with the Creator. Thus even the most degraded labour became dignified. Lynn White, argued that this was a distinctive feature of the religious approach and the piety of Western Christianity, which emphasizes good work, in contrast to the contemplativeness of Eastern Christianity and explained, the favourable attitude towards technological progress in Western Europe in the Middle Ages.[3]

[2] Lynn White Jr., *Technology and innovation in the Middle Ages,* (in his volume) *Medieval Religion and Technology* (Univ. of California Press 1978), p. 22; idem, *Cultural elements and technological advance in the Middle Ages,* (in the same volume), p. 227.

[3] *Technology and innovation,* l.c.; *Cultural elements and technological advance in*

The connection between intellectual attitudes and technological development may be valid for the later Middle Ages, fails to take account of the great advance of Byzantine and Islamic technology in the early Middle Ages. When the Byzantines constructed their superb domes and the Moslems invented the refining of sugar and introduced Chinese paper production into the Levant their style of piety was already very different from that of Western Christianity.

Many historians have argued that the influence of foreign civilisations was an important factor in the development of technology in medieval Europe. Many innovations may have followed the transmission of inventions from the Near or even the Far East. However, most of these arguments lack archival evidence or are simply erroneous. One prominent orientalist has claimed, for instance, that the lateen sail and the compass, two important innovations of medieval shipping, were taken over by the Europeans from the Moslem world.[4] In fact the lateen sail was used in the Mediterranean in Roman times and came into use again in the Byzantine navy between the sixth and the ninth centuries.[5] The mariner's compass was originally a Chinese invention. However the Chinese used a floating compass, whereas in southern Europe the magnetic needle was amalgamated with the windrose that is attached to a compass card, so that it moved together with it and turned when the ship changed direction.[6]

the Middle Ages, p. 246 ff.; idem, *The iconography of Temperantia and the virtuousness of technology*, (in the same volume) p. 204; idem, *The expansion of technology, 500-1500*, (in) *The Fontana Economic History of Europe, The Middle Ages* (London 1972), p. 170 f.

[4] W. Montgomery Watt, *The influence of Islam on Medieval Europe* (Edinburgh 1972), p. 20, 21.

[5] Lynn White, *The diffusion of the lateen sail*, (in his volume quoted above), p. 212 ff.; Paul Adam, *A propos des origines de la voile latine*, (in) *Mediterraneo e oceano indiano, Atti del Sesto Colloquio Int. di Storia Marittima*, Venezia 1962 (Florence 1970), p. 212.

[6] K. Kretschmer, *Die italienischen Portolane des Mittelalters* (Berlin 1909), p. 70, 74, 80 f.; Bachisio R. Motzo (ed.), *Il compasso da navigare* (Cagliari 1947) (Annali della Facoltà di lettere e filosofia della Università di Cagliari VIII), p. LXXXIV.

The phenomenon of "parallel" invention, that is, inventions made independently of each other but stemming from the same needs, played a great role in the development of technology in the past when communication was much slower than today. Lynn White, who is a great authority in this field, is also aware of this fact.[7] Nevertheless he is inclined to assume the Central Asian origin of the new horse collar, used in Europe from the early Middle Ages.[8] Nor does he admit that printing by means of moveable cast types which was developed in the mid-XVth century in the Rhineland, was a Korean invention transmitted to the Europeans or that firearms had a Chinese origin.[9] Neither does he believe that the mechanical crank was taken over from the Far East.[10] However, Lynn White does believe firmly in a more or less steady flow of technological inventions from India and China to Western Europe. King Alfred the Great, for example, sent a mission to India [11] and in the later Middle Ages Tatar slaves would have been the vehicle of transmission of technology.[12]

One cannot deny that technological innovations were transmitted from one geographical region to another. Despite chronic warfare the countries of the Christian Occident Byzantium, the Caliphate and their successor states formed a region. Cotton planting and the growing of sugar cane were certainly introduced in Sicily by the Moslems and it is well known that the

[7] See his paper *Medieval borrowings from Further Asia*, (in) *Medieval and Renaissance Studies*, ed. O.B. Hardison Jr. (Chapel Hill, Univ. of North Carolina Press 1971), p. 5.

[8] *Art. cit.*, p. 10 f.

[9] *Technology and innovation in the Middle Ages*, p. 8 ff.

[10] *Medieval borrowings from Further Asia*, p. 11.

[11] *Art. cit.*, p. 6; in fact this assumption is due to the error of a medieval copyist who wrote *India* instead of *Judaea* (which the emissaries visited), see *The Anglo Saxon Chronicle*, ed. B. Thorpe (London 1861) I, p. 152 II, p. 66; WILLELMI MALMESBURENSIS MONACHI, *De gestibus regum Anglorum*, ed. W. Stubbs (London 1887) I, p. 130; M. KRATOCHWILL, *Eine Reise von Sendboten* König Alfreds des Grossen nach Indien, "Mitt. der Geogr. Gesellschaft zu Wien" 81 (1938), p. 227 ff.

[12] *Medieval borrowings from Further Asia*, p. 20 f.

Swabian Emperor, Frederick II, invited Syrian technicians to improve the sugar production in Sicily.[13] But it is questionable whether the methods of production were transferred from Arabic cotton weavers in Sicily to those on the Italian mainland. M.F. Mazzaoui, in her excellent book, surmises that slaves or Jews fulfilled this role. She also believes that the bow used for beating cotton travelled from Sicily to the Italian mainland.[14] These suppositions, however, are not substantiated by documented facts.[15] Mazzaoui also assumes that the treadle-loom was of Oriental origin while she sees the use of Oriental names for cotton fabrics as evidence of the transmission of methods of production. She also argues that Italian cotton weavers took over only some of the methods of the Orientals, since famous fabrics like the mulham cloth were not produced in Italian workshops.[16] But the texts used by Professor Mazzaoui to prove the Sicilian origin of the Italian cotton industry do not refer to cotton weaving but to cotton planting and linen production.[17] The assumption that the treadle-loom was transmitted from the Near East via Sicily to Italy is a mere hypothesis,[18] while the use of Oriental names for certain textiles does not prove that production methods were copied. Finally, the fact that mulham cloth (a textile whose warp was of silk and the woof of cotton) was not produced in Italy, does not point to a "funnel effect" (transmission of a part of the production

[13] W. Heyd, *Histoire du Commerce du Levant au Moyen-Âge* (Leipzig 1885-86) II, p. 686.

[14] *The Italian Cotton Industry in the Later Middle Ages* (Cambridge Univ. Press 1981), p. 66, 76.

[15] As to the use of the bow, the author can produce only one document dating from 1110 and Apulia.

[16] *Op. cit.*, p. 82 f., 89 f.

[17] al-Mukaddasi, *Ahsan at-takasim*, p. 145; M. Amari, *Storia* [2] (Catania 1933-37), III, p. 826; D. Abulafia, *The Two Italies* (Cambridge Univ. Press 1977), p. 38, 47, 48, 218, 221, 255, 283; R.B. Serjeant, *Material for a history of Islamic textiles up to the Mongol conquest*, "Ars Islamica" 15/16 (1951), p. 55 f.

[18] A. Geijer, *Technical Viewpoints on Technical Designs* (in) *Artigianato e tecnica nella società dell'alto medioevo occidentale, 18ª Settimana di studio, Centro italiano di studi sull'alto medioevo* (Spoleto 1971), p. 694.

methods only) as Professor Mazzaoui supposes, since the mulham cloth was a typical product of Eastern Persia only.[19]

Marxist historians generally believe that slavery (and forced labour) impeded technological progress. But it is essential to set this problem in its context, because both in Near Eastern Moslem civilisation and in medieval Western Europe slavery and forced labour (in various forms) played a great role.[20] If the Marxist thesis is correct, the replacement of slavery and serfdom by free labour would have generated technological progress.

Marx and Engels outlined their views on technological progress and decline when dealing with the civilisation of the Ancients. Thus argued that Greco-Roman civilisation was essentially a slave-holder society, and the employment of great numbers of slaves for manual work resulted in the debasement and general disdain of physical labour causing technological stagnation. These arguments are maintained by Marxists to this day.[21] Although Marxist economic historians are not consistent about the character of Roman society and the impact of slave labour upon the development of technology, some Marxist scholars have admitted that free labour represented a major sector of production in the Roman Empire, although even these historians emphasised the negative influence of slavery upon technological advance.[22] Another team of Marxist archaeologists concluded from a detail study of Roman ceramics and other sec-

[19] See ATH-THA'ALIBI, *Lata'if al-ma'arif*, transl. C.E. Bosworth (Edinburgh 1968), p. 28, 145; AL-MUKADDASI, p. 323, 325; R. DOZY, *Dictionnaire détaillé des noms des vêtements chez les Arabes* (Amsterdam 1845), p. 113; idem, *Supplément aux dictionnaires arabes*, II, p. 522. (But of course *mulham* appears sometimes in documents of the Near East, see E. ASHTOR, *Histoire des prix et des salaires dans l'Orient médiéval*, [Paris 1969], p. 152).

[20] E. ASHTOR, *A Social and Economic History of the Near East in the Middle Ages* (London 1976), p. 201 (for forced labour employed in State industries).

[21] See F. VITTINGHOFF, *Die Theorie des historischen Materialismus über den antiken "Sklavenhalterstaat"*, "Saeculum" 11 (1960), p. 89 ff., 127 f.

[22] E. CICOTTI, *Le declin de l'esclavage antique* (Paris 1910), p. 284 f., 287 ff., 295, 413 ff., 419; see further K. KAUTSKY, *Sklaverei und Kapitalismus*, (in) "Die Neue Zeit" 29, part 1 (1911), p. 720, 722, 723.

tors of industrial production that at the heyday of Roman power, slavery reached its apogee and that the employment of slaves in great enterprises impeded technological advance.[23]

But non-Marxist historians have time and again emphasized that slavery was never the predominant system of production in either sector.[24] A more persuasive argument which disproves the Marxist analysis is that Roman technology made the greatest progress especially in methods of agricultural work during the first century B.C.,[25] while the finest Roman pottery, produced in the same period in Arezzo, was manufactured by slaves. Even Soviet historians admit to this fact.[26] One must also ask why Roman technology made insignificant progress in the early republican period when there was relatively little slavery, while it is obvious that the decline of slavery in the later empire did not result in technological advance.[27]

A Dutch historian has maintained that technology did not advance in the Roman Empire because the availability of labour made labour-saving devices almost unnecessary.[28] This thesis has great importance for the interpretation of technological progress (and stagnation) in the medieval period. But if it were correct, one would have difficulty in explaining the considerable advance of technology in the caliphate. In fact when the Barme-

[23] A. Carandini, *Sviluppo e crisi delle manufatture rurali e urbane*, (in) *Società romana e produzione schiavistica* III, ed. A. Carandini e A. Schiavone (Bari 1981), p. 250, 258.

[24] M.L. Finley, *Ancient Slavery and Modern Ideology* (London 1980), p. 79, 81, 85; A.H.M. Jones, *The Later Roman Empire* (Oxford 1964) II, p. 851, 860, 862.

[25] B. Gille, *Lents progrès de la technique*, "Revue de synthèse", n.s. 32 (1953), p. 76 f.; M.L. Finley, *Technical innovation and economic progress in the ancient world*, "Economic History Review" 2nd series, 18 (1965), p. 35, 43; Fr. Kiechle, *Sklavenarbeit und technischer Fortschritt im römischen Reich* (Wiesbaden 1969), p. 170 f.

[26] E.M. Štaerman, *Die Blütezeit der Sklavenwirtschaft in der römischen Republik* (Wiesbaden 1969), p. 110.

[27] Fr. Kiechle, *Sklavenarbeit und technischer Fortschritt*, p. 173; Finley, *Ancient Slavery and Modern Ideology*, p. 138.

[28] H.W. Pleket, *Technology and society in the Graeco-Roman world*, "Acta Historica Nerrlandica" II (1967), p. 13.

kids introduced Chinese paper production in the Abbasid Caliphate and later when the Egyptians learned to refine sugar, the availability of labour was so great that the price of labour went down steadily and continuously.[29] The same Dutch historian provided another explanation for technological stagnation in the ancient world when he claimed that the emphasis of Greek and Roman education on rhetoric and literature was an obstacle to technological progress. This is an interpretation that is widely shared among classical scholars. But others have argued that the Ancients were interested in technological progress in order to increase luxury.[30] This interpretation is again pertinent for the analysis of medieval economies, since in Moslem countries new techniques were invented mainly for the sake of luxury and pleasure.[31]

Another interpretation of technological development has stressed the decisive impact of demographic change. Population growth encouraged the advance of technology, while depopulation had the reverse effect. Considerable technological progress was made in Athens — particularly in mining and shipbuilding — in the sixth and fifth centuries B.C., while the technological advance of the Roman Empire in the first century B.C. and the first century A.D. was also concomitant with population growth. In the Middle Ages technologies were greatly improved in the XIth-XIIIth centuries when population increased everywhere, while these developments ended towards the end of the XIIIth century when population declined.[32] In short, the need to feed greater numbers of people encouraged the introduction

[29] E. Ashtor, *I salari del medio oriente durante l'epoca medievale*, RSI 78 (1966), p. 329.

[30] Fr. Kiechle, *Das Problem der Stagnation des technischen Fortschritts in der römischen Kaiserzeit*, (in) "Geschichte in Wissenschaft und Unterricht" 16 (1965), p. 97.

[31] E. Wiedemann, *Aufsätze zur arabischen Wissenschaftsgeschichte* (Hildesheim 1970) I, p. 75 note a, 100 ff. II, p. 48 ff., 471 ff., cf. 478; Carra de Vaux, *Les mécaniques ou l'élevateur de Héron d'Alexandrie*, "Journal Asiatique" 1893, I, p. 419 II, p. 499, 505, 507.

[32] B. Gille, *Lents progrès de la technique*, p. 74, 76, 79, 81.

of labour-saving machines and innovations which increased the supply of commodities.[33] The data concerning the development of technology in the Caliphate could certainly be an additional argument for this hypothesis. Even there, methods of industrial production were considerably improved and new industries were founded when population increased.

However, important innovations were made in late medieval Europe when the curve of demographic development was at an ebb. From the end of the XIIIth century the use of the spinning wheel spread in Western Europe; in about 1330 the mechanical clock was invented; from the middle of the XIVth century the use of water-power in various sectors of industrial production became general and in the XVth century there was a great upswing in mining and mechanics due to the invention of the bit and brace and the reverberatory furnace (*seigern*).[34] Historians who claim that demographic development was the decisive factor in technological changes are surely aware of the critical importance of capital supply. Why is it that present-day India, which enjoys a true demographic boom, is not one of the most technologically advanced countries? There are indeed different responses to population growth, which may result either in an outburst of innovations or in the fall of per capita income.[35]

The spectacular upswing of technology which took place in Western and Central Europe in the period after the Black Death may be explained by the fact that many people enjoyed great well-being so that high quality commodities were in demand. This could explain the improvement of the production of woollens with the introduction of carding.[36] However, this inter-

[33] F.M. Feldhaus, *Die Technik der Antike und des Mittelalters* (Potsdam 1931), p. 425.

[34] Lynn White, *The expansion of technology, 500-1500*, p. 160.

[35] J.A. Schumpeter, *The creative response in economic history*, "Journal of Economic History", VII (1947), p. 149 f. (but it also happens that population growth brings about both phenomena, e.g., in the Caliphate...).

[36] G. Gille, (in) M. Daumas, *A history of Technology & Invention* II (New York 1969), p. 92.

pretation is not tenable for the development of other industries in late medieval Europe. W. von Stromer's work on the birth of the South German fustian industry at the end of the XIVth century, rightly raised the question of how the founders of this new industry overcame the opposition of the linen weavers, who were very much attached to their craft. The answer, according to W. von Stromer, was that the Black Death and subsequent epidemics had decimated the linen weavers leaving a vacuum which made it possible to found a new industry.[37] This hypothesis is contrary to the supposed correlation between demographic growth and technological advance. But the decline of Near Eastern industries in the later Middle Ages, when the region suffered from a great shortage of labour, would also disprove this hypothesis and points to the impact of government policies on industrial development since in the period immediately subsequent to the Black Death the Near Eastern countries still had a strong class of capitalists who were certainly interested in improving production methods and increasing their profits.

II

Against the all-embracing theories which single out one factor as decisive for the development of technology in the preindustrial period, one should emphasize the importance of other phenomena such as the migration of workers and the introduction of new raw materials, two occurrences which were often correlated. In the Middle Ages foreign workers introduced new techniques everywhere, while the use of new raw materials was often conditioned by the employment of foreign workers. They brought with them new methods adapted to the use of certain raw materials.[38] Even in the Moslem countries in the days of the

[37] W. von Stromer, *Die Gründung der Baumwollindustrie in Mitteleuropa* (Stuttgart 1978), p. 138 f.

[38] Mazzaoui, *The Italian Cotton Industry*, p. 67, 70; G. Mandich, *Privilegi per*

Caliphate and in the XIVth century, techniques were transmitted by workers who emigrated.[39]

Much data can be provided to show the great importance of worker migrations for the development of textile industries in medieval Europe. Flemish weavers developed the woollen industry in England in the 1330's [40] and worked in Vienna at the beginning of the XIIIth century.[41] Later, in the XVth century Flemish weavers were engaged in Saxony in order to raise the level of the wool production.[42] French clothmakers were employed in the wool industry of Genoa in the XIIIth century.[43] There was frequent migration of workers from one industrial centre to another in the same country. For various reasons weavers and other textile workers left their homes and went to another town where they introduced the production methods with which they were familiar. This happened very often in Italy in the later Middle Ages. The Florentine woollen workshops employed weavers, dyers and finishers from Lombardy and also from Germany.[44] When the Florentine industrialists decided to introduce the production of Perpignan cloth, foreign workers

novità industriali a Venezia nei secoli XV e XVI, (in) Deputazione di storia patria per le Venezie, Atti Asemblee 8. sett. 1963, p. 31.

[39] SERJEANT, *Material for a history of Islamic textiles*, "Ars Islamica" X (1943), p. 74 (about *dabiki* produced in Fars); C.J. LAMM, *Mittelalterliche Gläser und Steinschnittarbeiten aus dem Nahen Osten* (Berlin 1930), p. 247; E. ASHTOR in *X^a Settimana di Studio, Istituto Fr. Datini* (Florence 1983), p. 417 f.

[40] H.-E DE SAGHER, *L'immigration des tisserands flamands et brabançons en Angleterre sous Edouard III*, (in) "Mélanges d'histoire offerts a H. Pirenne" (Bruxelles 1926), p. 109 ff.

[41] H. AMMANN, *Deutschland und die Tuchindustrie Nordwesteuropas* (in) "Hansische Geschichtsblätter" 72 (1954), p. 61.

[42] R. SPRANDEL, *Zur Geschichte der Wollproduktion in Nordwestdeutschland*, I^a Settimana di studio, Istituto Fr. Datini (Florence 1974), p. 101.

[43] R. DOEHAERD, *Les relations commerciales entre Gênes, la Belgique et l'Outremont d'après les archives notariales génoises aux XIII^e et XIV^e siècles* (Bruxelles-Rome 1941), I, p. 175, 197.

[44] G.A. BRUCKER, *Florentine Politics and Society, 1343-1378* (Princeton University Press 1962), p. 150; about the role of the Umiliati in Florence see A. DOREN, *Die Florentiner Wollentuchindustrie vom vierzehnten bis zum sechzehnten Jahrhundert* (Stuttgart 1901-08), II, p. 28 ff.

were once more brought to the town.[45] In fact most medieval textile centres not only produced a characteristic type of cloth, but also imitated the products of other towns. For this purpose they had, at least in the beginning, recourse to the skill of foreign workers. When the Venetians embarked on the imitation of Florentine *garbo* cloth, they engaged Florentine textile workers.[46] Silk weavers of Lucca introduced their own local methods to Venice in the beginning of the XIVth century.[47] On the other hand, Venetian weavers worked in Padua [48] and Venetian dyers were employed in the Swabian linen industry. They taught the Germans to use dyes according to the Venetian fashion.[49]

Sometimes workers who later introduced production methods of their town to another industrial centre and spread what was considered a professional secret, had left home for political reasons, for example when a certain political party was defeated and its members persecuted or exiled. This happened often in medieval Italy. But various townships and princes who ruled industrial towns made efforts to induce foreign workers to settle on their territory and to develop industries and promised them privileges such as tax exemption, if they wished to accept their invitation.[50] The township of Bologna in the XIIIth century granted several privileges, including financial assistance, to foreign textile workers from Verona and other towns.[51]

[45] Doren, *op. cit.*, p. 96.

[46] H. Hoshino, *L'Arte della Lana in Firenze nel Basso Medioevo* (Florence 1980), p. 247.

[47] T. Bini, *Su i Lucchesi a Venezia. Memorie dei secoli XIII e XIV*, "Atti della R. Accademia Lucchese" 16 (1857), pp. 174, 185, 238, 244 f.

[48] R. Cessi, *Le corporazioni dei mercanti di panni e della lana in Padova fino a tutto il secolo XV*, (in) "Memorie del R. Istituto Veneto di scienze, lettere ed arti" 28, no. 2 (1980), p. 48.

[49] W. von Stromer, *Die Gründung der Baumwollindustrie in Mitteleuropa*, p. 92.

[50] See Cessi, *art. cit.*, p. 48 f. about a decree of Francesco da Carrara, ruler of Padua, in 1365; Mazzaoui, *op. cit.*, p. 71.

[51] M.F. Mazzaoui, *The emigration of Veronese textile artisans to Bologna in the*

Thus great and even minor centres of the textile industry employed a considerable number of foreign workers, who contributed by introducing the manufacturing methods of their home towns to the development of the cloth industries. In Vicenza there were workers from Bergamo, Como, Crema, Verona and even from Germany and Flanders. In the middle of the XVth century the influx of German clothmakers to Vicenza was particularly strong.[52]

The intense migratory movement of textile workers resulted in the same raw materials and manufacturing methods being used in various towns. In cloth manufacturing in Venice the same types of wool as those of Verona and Bologna were used.[53] On the transmission of manufacturing methods, one might also mention the role of the textile workers of Verona who emigrated in 1230/1 to Bologna, where they introduced the measurements of Veronese cloth.[54] The introduction of new methods of cloth-making was certainly most important for the medieval textile centres. The dyeing of textiles learned from foreign craftsmen had enormous importance in the Middle Ages. The numerous shades of different colours were very much sought after and the employment of foreign dyers had a great impact on the textile manufacturers in all countries.

There is a great deal of information on the activities of textile workers who emigrated to other countries, and the influence of migrant skilled workers in other branches of medieval industry can also be traced.

The Germans played a major role in the development of mining in numerous European countries, and were also consi-

thirteenth century, "Atti e Memorie della Accademia di Agricoltura, Scienze e Lettere di Verona", ser. VI, vol. 19 (1967-68), p. 275 ff. 279.

[52] G.B. Zanasso, *L'arte della lana in Vicenza (secoli XIII-XIV),* (in) "Miscellanea di storia veneta", ser. III, t. VI (Venice 1914), p. 70, 97, 314 ff., 353 ff., 369 ff.

[53] E. Rossini-M.F. Mazzaoui, *Società e tecnica nel medioevo. La produzione di panni di lana a Verona nei secoli XIII-XIV-XV,* (in) "Atti e Memorie della Accad. di agricoltura, scienze e lettere di Verona", ser. VI, vol. 21 (1971), p. 592 f.

[54] Mazzaoui, *The Italian cotton industry,* p. 84.

dered great experts in many branches of metallurgy and were readily engaged everywhere.[55] The production of mirrors was introduced into Venice by German and French craftsmen,[56] while the skill of German cannonmakers ("bombardieri") was highly appreciated in Italy in the XVth century. Many townships employed them.[57] German gunmakers were also employed in France.[58] In Italy, after 1461,[59] French and German printers spread the new art of using moveable types, while Italian papermakers introduced the art of producing rag paper for Nüremberg.[60]

The importance of the migration of skilled workers for the spread of technological innovations (which were often considered as professional secrets) was brought home with a vengeance by the measures taken against it by various governments. The great number of decrees enacted to this effect bears testimony to the apprehension of the industrial centres. The Senate of Venice even forbade the teaching of glassmaking to foreigners,[61] and ship-patrons were warned not to accept as passengers skilled artisans who wanted to emigrate from Venice.[62] Craftsmen who emigrated were threatened by many governments with heavy punishment,[63] and sometimes they were even threatened with the death penalty and those who would kill

[55] *Itinerario di Marino Sanuto per la terraferma veneziana nell'anno MCCCCXXXIII* (Padua 1847), p. 123.

[56] A. Casparetto, *Il vetro di Murano dalle origini ad oggi* (Venice 1958), p. 161 ff.

[57] B. Rathgen, *Das Geschütz im Mittelalter* (Berlin 1928), p. 29.

[58] R. Gandilhon, *Politique économique de Louis XI* (Paris 1941), p. 205.

[59] H.F. Brown, *The Venetian Printing Press, 1469-1800* (London 1891), chapter I.

[60] E. Marabini, *Die Papiermühlen im Gebiet der weiland freien Reichsstadt Nürnberg* (Nürnberg 1894), p. 17 ff.

[61] ASV (Archivio di Stato, Venezia), Senato Terra X, f. 177a f.

[62] Senato Terra l. c.

[63] Florence; Doren, *Die Florentiner Wollentuchindustrie* II, p. 76, 570 f.; Venice: G. Monticolo, *I capitolari delle arti veneziane*, vol. II, part. 1, (Rome 1905), p. 88 f.; B. Cecchetti, *Sulla storia dell'arte vetraria muranese* (Venice 1865), p. 31, 32; L. Zecchin, *Nuovi appunti di storia vetraria muranese* (Venice 1958), p. 5 ff.

them were promised a reward.[64] However, there were also numerous decisions to grant the emigrated workers facilities in order to induce them to return.[65]

While the emigration of workers was an event which affected the population of both the town (or country) they left and the town where they settled, there is much less data about the introduction of new raw materials in a particular industrial centres, although this often had a major impact on industrial production and often made it necessary to adopt new methods of production.

The importance of English wool in the cloth industry of Florence is well known. In other Italian textile centres in the later Middle Ages, the kind of wool used for the manufacturing of various cloth also changed from time to time.[66] A great variety of dyes were also employed in the European textile industry,[67] and the import of Oriental dyes was accompanied by the transmission of methods of dying. The Orientals were great experts in the use of mineral mordants. At first they used old olive oil mixed with a soda solution, so that a precipitate of sodium oleate (especially of cotton) remained on the fibres. This sediment reacted during the following treatment by salts, calcic or tin salts. When madder was then added, the red colour was particularly durable.[68] The introduction of alum, of which great quantities had been imported into Southern Europe from the Levant since the Crusades, brought great improvements to the manufacture of textiles. There is much evidence that the Europeans esteemed the Oriental dyers as great experts [69] and in both the

[64] A. Schwarz, *Der Haspel*, "Ciba-Rundschau", Heft 64 (1945), p. 2357.

[65] L. Zecchin, *Cronologia vetraria veneziana e muranese*, "Rivista della Stazione sperimentale del vetro (Murano)" III (1973), p. 165, 213, 216, 257.

[66] N. Fano, *Ricerche sull'arte della lana a Venezia*, "Archivio Veneto", ser. V, vol. 18 (1936), p. 153 f.

[67] See E. Ashtor, *L'ascendant technologique de l'Occident medieval*, "Revue suisse d'histoire" (1983), p. 392.

[68] E.E. Ploss, *Ein Buch von alten Farben* (Heidelberg 1962), p. 39 ff.

[69] See A. Lombardo, *Un testamento e altri documenti in volgare siciliano del*

textile and glass-making industries the European dyers did their best to imitate them. Successful dyeing was of major importance even for this flourishing medieval industry,[70] and Venice, the leading commercial town in the Levant trade, played a major role in the transmission of Oriental dyeing methods to the West.

The variety of raw materials used in the famous glass industry of Murano was particularly great and induced the glaziers to develop new methods. The glassmakers of Murano used pebbles from the river Ticino, which contained high quantities of silicate, for producing fine crystal glass.[71] To make the glass clear, manganese from Piedmont was also used.[72] For the dyeing of glass, the Muranese used cobalt from Germany,[73] and Italian glassmakers in the later Middle Ages also commonly used *ferretto* (oxide of copper) to produce green enamelled glass.[74]

The great advantages that came from using new raw materials is clearly seen in the outstanding work of the Muranese glassmakers in the XVth and XVIth centuries. The great progress that resulted from the use of high quality raw materials also made other achievements possible, such as the invention of spectacles, an instrument of major importance for the intellectual development of mankind, which followed the production of clear glass in about the year 1280 in Italy.[75] The date of the in-

secolo XIV a Venezia, "Bollettino del Centro di studi filologici e linguistici siciliani" 10 (1969), p. 59.

[70] L. Zecchin, *I "segreti" dei vetrai muranesi del Quattrocento*, "Riv. Staz. sper. del vetro" 11 (1981), p. 167 f.

[71] Ant. Neri, *L'arte vetraria, 1612*, ed. R. Barovier Mentasti (Milan 1980), p. 4; *Dell'arte del vetro per musaico tre trattatelli*, ed. G. Milanesi (Bologna 1864) I, chap. 6 (the first and the second treatise are of Muranese inspiration).

[72] L. Zecchin, *Materie prime e mezzi d'opera dei vetrai nei documenti veneziani dal 1439 al 1452*, "Riv. Staz. sper. del vetro" 12 (1982), p. 65.

[73] W. Ganzmüller, *Uber die Verwendung von Kobalt bei den Glasmachern des Mittelalters*, (in his volume) *Beiträge zur Geschichte der Technologie und der Alchemie* (Weinheim 1956), p. 171.

[74] *Dell'arte del vetro*, chapter 88 (this is a Florentine treatise).

[75] L. Zecchin, *I "roidi da ogli"*, "Giornale economico" (of the Camera di commercio, industria e agricoltura di Venezia) 1962, p. 438 ff.; idem, *I "rodoli di vero"*, ibidem p. 688 ff.; idem, *Cronologia vetraria veneziana e muranese dal 1286 al 1301*,

vention coincides with the first references to the import of the excellent Syrian alkali ashes which formed the basic raw material of the Murano glass industry.[76]

In discussing the impact of the introduction of new raw materials on the progress of technology in medieval Europe, it is important to emphasize once more the great difference between conditions of industrial production in Western Europe and in the Near East in this period. Although the Near Easterners imported high quality raw material from far-away regions, such as saffron from Southern Europe, which was used for dyeing, oxide of copper and others, these were small shipments of very expensive articles. The importing of large quantities of other basic raw materials was unthinkable under the economic and social conditions of the late medieval Levant.

III

As well as the migration of skilled craftsmen and the use of new raw materials, the economic policy of the State in the later Middle Ages was another decisive factor in technological and industrial progress. Whereas in the modern period entrepreneurship probably played the greatest role in modernising industry, it was princes and governments of comunes who in the Middle Ages held the key to industrial development. This has already been argued by other historians, but requires fuller documentation.

There were numerous good reasons for princes and city governments to foster technological and industrial progress. Princes wanted to immortalize their names by erecting famous buildings, which gave a strong impetus to technology. Architects had

"Riv. Staz. sper. del vetro" III (1973), p. 66, 120. But according to F.M. Feldhaus this invention was made in Germany, see his *Die Technik der Antike und des Mittelalters*, p. 305.

[76] E. Ashtor-G. Cevidalli, *Levantine alkali ashes and European industries*, JEEH 12 (1983), pp. 487-90.

to improve methods and engineers invented new instruments while it was also necessary to ensure sufficient supply of the commodities needed by the subjects and to supply work. Full employment of the population was at the top of the agenda of medieval rulers just as it is today. But although other political reasons, such as conflicts with other countries, also induced princes to foster industrial enterprises, the strongest incentive came from the desire to increase stocks of money by increasing exports and to reducing imports. This was probably the major consideration for the rulers.

Sometimes different objectives were combined, such as improving economic conditions and achieving fame. This was surely true of Francesco Sforza, the ruler of Milan (1450-66), who embarked on great hydraulic projects to control the level of the river Po and open navigable waterways for his capital. In the years 1457-60 the Martesana canal, connecting Milan with Lake Como, was constructed and then another canal, leading from Milan to Pavia. Important innovations accompanied the construction of these canals, such as locks with moveable gates.[77] But the Montefeltro rulers of Urbino had different motives. They were primarily interested in military engineering and their team of splendid technicians and architects scored great achievements in the building of fortifications and palaces, which also led to important inventions in hydraulics and mechanics.[78]

The patronage of engineers and architects was typical of the Renaissance princes who were imbued with the ideas of humanism, while the measures taken by other princes and comunal governments show the growing influence of mercantilist ideas. Princes and townships sought to protect local products from foreign competition either by imposing or increasing import duties or by forbidding the imports altogether. They also attempted to increase the supply of raw materials and to im-

[77] B. Gille, (in) M. Daumas, *A history of technology & invention* II, p. 27.
[78] *Op. cit.*, p. 27 f.

prove their quality, while measures were taken to encourage import of capital and to inhibit export, and new industries were fostered by inviting foreign skilled workers and entrepreneurs. The strict supervision of industrial production was another aspect of this new departure.

There is ample evidence of the ways in which princes and cities in the late Middle Ages attempted to foster technological progress. As textile manufacturing was the most important sector of medieval industry, the measures taken by different governments were aimed principally at its promotion.

The German kings of the Luxemburg dynasty took a number of steps to strengthen the trade and industry of their countries. Sigismund, King of Germany and Hungary (and later Emperor) founded a privileged cotton industry in Košice [Eastern Slovakia] in 1411.[79] Louis XI of France, who systematically pursued a mercantilist policy, introduced the silk industry in his country by employing Italian specialists.[80] The Angevins of Naples made efforts to develop a woollen industry which could compete with those of other countries. Charles I of Naples gave orders to import sheep from North Africa in order to provide the workshops with better wool.[81] His son and successor Charles II made agreements with the Umiliati and Florentine industrialists to establish workshops in Naples.[82] Then King Robert brought Florentine industrialists to Naples to establish the manufacture of woollens.[83] In 1327 the town council of Na-

[79] W. von Stromer, *Die Gründung der Baumwollindustrie in Mitteleuropa*, p. 92.

[80] Gandilhon, *Politique économique de Louis XI*, p. 176 ff.

[81] C. Minieri Riccio, *Nuovi studi riguardanti la dominazione angioina nel regno di Sicilia* (Naples 1876), p. 14.

[82] G. de Blasiis, *La dimora di Giovanni Boccaccio a Napoli.* "Arch. Stor. per le prov. nap." 17 (1892), p. 97; see also Cerone, "Arch. Stor. Nap." 27, p. 492 f.; G. Yver, *Le commerce et les marchands dan l'Italie méridionale au XIII^e & au XIV^e siècle* (Paris 1903), p. 86 f.; G. Coniglio, *L'arte della lana a Napoli*, "Samnium" 21 (1948), p. 62.

[83] M. Camera, *Annali delle due Sicilie*, II (Naples 1860), p. 215; N.F. Faraglia, *Storia dei prezzi in Napoli dal 1131 al 1860* (Naples 1878), p. 95; Yver, *op. cit.*, p. 88

ples granted facilities to a Florentine for industrial activities.[84] In the second half of the XVth century King Ferrante of Naples made further efforts to foster the textile industry of his country. In 1465 he forbade the import of foreign cloth and in 1480 he granted privileges for establishing workshops in Naples to Spanish, Florentine, Bolognese and Milanese industrialists.[85] Like his father before him, he also invited silk production experts to Naples.[86] Even the Aragonese kings of Sicily tried to develop the production of high quality cloth in their country. In 1309 a contract was made with the Umiliati to establish a workshop in Palermo[87] and in 1322 another attempt was made, this time by the town council of Palermo.[88] The governments of the Renaissance period not only invited foreign industrialists to settle in their territories, but also took measures to raise the technological level of production. For instance fulling the cloth by the feet was forbidden.[89]

So far we have quoted measures taken by powerful kings to foster industrial progress, but princes of lower rank and small communes did the same. The measures taken by these rulers and lawgivers referred expressly to technological innovations.

The statutes of the silk guild of Florence contained the stipulation that foreign inventors be encouraged to settle in the

f.; R. Caggese, *Roberto d'Angiò e i suoi tempi* (Florence 1922), I, p. 531; Coniglio, *art. cit.*, p. 62 f.

[84] Camera, *op. cit.*, p. 332.

[85] Faraglia, *op. cit.*, p. 99; Coniglio, *art. cit.*, p. 64 f.

[86] G. Tescione, *L'arte della seta a Napoli e la colonia di S. Leucio* (Naples 1932), p. 16 ff.; about an agreement of the duke of Salerno with Sienese clothmakers to establish a woollen industry in Amalfi see M. Aymard, *Commerce et consommation des draps en Sicile et en Italie méridionale*, II[e] Settimana di studio, Istituto Fr. Datini (Florence 1976), p. 137 f.

[87] G. Giulini, *Memorie spettanti alla storia, al governo ed alla descrizione della città e della campagna di Milano ne' secoli bassi* (Milan 1760), VIII, p. 585; cf. Sac. I. Carini, *Le pergamene cremonesi nel Grande Archivio di Palermo*, "Archivio Storico Siciliano", n.s. II (1877), p. 227 f.; C. Trasselli, *Tessuti di lana siciliani a Palermo nel XIV secolo*, "Economia e Storia", III (1956), p. 304 f.

[88] G. Pipitone-Federico, *Di un lanificio palermitano della prima metà del secolo XIV*, "Arch. Stor. Sic.", n.s. 37 (1913), p. 303 ff.

[89] Fano, *Ricerche*, p. 196.

town.[90] Specialists of other crafts were also invited to come to Florence.[91] Venice granted facilities such as housing and workshops to those who came to found workshops in its territory.[92] Foreign shipbuilders who claimed to have invented new schemes were encouraged to settle in Venice.[93] The rulers of Verona, the Scaligeri family, made great efforts to encourage foreign textile workers to settle on their territory.[94] Even small towns such as Udine tried to develop a cloth industry in the XIVth century by encouraging foreign workers to settle amidst their subjects.[95] In Germany too some city councils attempted to establish textile industries by engaging foreign weavers. The councils of Munich, Speyer and Dinkelsbühl made agreements to this effect at the beginning of the XVth century.[96]

The granting of privileges to entrepreneurs was only one of the measures taken by different governments to foster industrial progress. Some governments placed machinery at the disposal of industrialists which guaranteed the high quality of products. In the year 1332, for example, it was decided in Venice to grant a plot of land and a loan for the construction of a windmill to Bartolomeo Verdi.[97] In 1375 the senate of Venice allowed 1000 ducats for the construction of a fulling mill in order to promote the woollen industry.[98] The Carrara rulers of Padua, too, constructed fulling mills for the town's cloth industry.[99] In Germany some townships took similar measures, and the town

[90] DOREN, *op. cit.* II, p. 542 f.

[91] G. GAYE, *Carteggio inedito d'artisti dei secoli XIV, XV, XVI* (Florence 1829-49) I, p. 547.

[92] *Le deliberazioni del Maggior Consiglio di Venezia* (Bologna 1931-50), II, p. 62.

[93] ASV, Senato Misti 60, f. 17.

[94] ROSSINI-MAZZAOUI, *Societa e tecnica nel medioevo*, p. 606 f.

[95] A. DI PRAMPERO, *Il dazio dei panni e l'arte della lana in Udine dal 1324 al 1368* (Udine 1881), p. 25 f., 27 ff.

[96] W. VON STROMER, *Die Gründung der Baumwollindustrie in Mitteleuropa*, p. 95, 96, 98 f.

[97] G. ZANETTI, *Dell'origine di alcune arti principali appresso i Veneziani* (Venice 1758), p. 74.

[98] ASV Senato Misti 34, f. 140b.

[99] R. CESSI, *Le corporazioni dei mercanti di panni e della lana in Padova*, p. 46.

council of Breslau, for instance, built a bleachery for the linen industry in 1359.[100]

The policy of promoting technological and industrial progress was by no means restricted to the textile industry. With the development of the new rag paper industry and later the art of printing in several advanced countries, further government measures were taken to promote these initiatives. Venice, for instance, forbade the export of rags in 1373, so that the papermakers would not suffer a shortage of raw material.[101] The importance of the new art of printing also quickly aroused the interest of farsighted governments, and Charles VII of France sent a gifted technician, Nicolaus Jenson of Sommevoire (near Troyes), to Mainz in 1458 to learn the secrets of printing so that he could later open a printing press in his own country.[102]

IV

In the XVth century the promotion of technological and industrial progress had become an integral part of the economic policy of the more advanced countries of Western and Southern Europe. It even had a distinctive term: *pro introducenda arte*. In the course of time the tendency of innovative governments to draw foreign technicians and industrialists to their countries, resulted in the granting of monopolies and patents. This was however a gradual development. Before the great step of fostering technological innovation was taken, the perception that inventors and innovators ought to enjoy certain privileges evolved slowly.

When the Venetian authorities granted permission to an entrepreneur in 1281 to build a windmill, he received no special

[100] H. Aubin, *Die Anfänge der grossen schlesischen Leinenweberei u. handlung*, "VSWG" 35 (1942), p. 120.

[101] H.F. Brown, *The Venetian printing press, 1469-1800*, p. 24.

[102] *Op. cit.*, p. 11.

rights.[103] But in 1323 a German engineer proposed to the Venetian government the construction of mills which would be sufficient for all the needs of the town and the Great Council agreed to pay the expenses.[104] In the year 1378 Giacomo da Albertin and Giuliano Sacchetto who proposed the building of windmills, were granted loans and the property of the plot of land where they were located.[105] Several licences for the use of dredging engines, so important for the town of the lagoons, were conceded by the Venetian authorities in the XIVth century and at the beginning of the XVth century with no special rights. Working tools were given to some of the technicians or housing facilities and tax exemption were granted to them.[106] The privileges granted in Bologna in 1341 to the son of Borghegnano for the use of a twisting mill for silk cannot be considered as a patent.[107] These technicians did not claim inventors' rights or monopolies. However, in the year 1416 an engineer from Rhodes obtained a mnopoly for a new kind of fulling mill in Venice, which is probably the first case of a patent granted to an inventor.[108] Five years later Filippo Brunelleschi, the architect who built the dome of Florence, received a monopoly for three years of transportation on the river Arno by a vehicle invented by him.[109] However, in the first half of the XVth century the granting of patents and monopolies was still the exception rather than the rule. But the governments of some Italian towns readily granted privileges to foreign technicians and industrialists *pro*

[103] *Deliberazioni del Magg. Consiglio*, II, p. 170.

[104] H. SIMONSFELD, *Der Fondaco dei Tedeschi in Venedig und die deutsch-venezianischen Handelsbeziehungen* (Stuttgart 1887), II, p. 292.

[105] B. CECCHETTI, *La vita de' Veneziani nel 1300* (Venice 1885), II, p. 58 f.

[106] *Op. cit.* I, p. 58, 61 f.

[107] W. ENDREI-W. VON STROMER, *Textiltechnische und hydraulische Erfindungen und ihre Innovatoren in Mitteleuropa im 14./15. Jahrhundert*, "Technikgeschichte" 41 (1974), p. 45. Already in 1236 Bonafusio de S.ta Columbia had obtained a licence for the production of new kinds of cloth in Bordeaux, see MANDICH, *Privilegi*, p. 29.

[108] G. MANDICH, *Primi riconoscimenti veneziani di un diritto di privativa agli inventori*, "Riv. di diritto industriale" VII (1958), p. 114.

[109] G. GAYE, *Carteggio*, p. 547 ff.

arte introducenda, for instance that of Milan in 1442 to a Florentine for the establishment of a silk industry [110] and that of Ferrara in 1446 to a Venetian for running a workshop of gold leaf. In the year 1462 a monopoly for silk production was granted in Ferrara for five years.[111]

In the middle of the XVth century a change in the character of these concessions occurred. In the year 1442 a Frenchman, Antoine Marin, proposed the construction of 24 mills which were not operated by waterpower to the government of Venice. He asked for a patent for 20 years and exemption from taxes. His offer was accepted.[112] Then in 1446 he obtained a privilege for his dredging machines in Venice.[113] Later in 1456 the same Frenchman, together with a fellow-countryman and a Venetian, obtained from Frederick III, archduke of Styria, a monopoly for the production of bricks of lime and the construction of mills and water canals. The concession was valid for 25 years and was to be passed on to their heirs and partners.[114]

The Venetian authorities granted several privileges in that period: in 1450 a privilege for building mills that was valid for 60 years, in 1460 a patent for dyeing engines and another for a machine which would raise water to be used by mills and in 1469 a patent was granted to the German printer Johann of Speyer. In the year 1471 a gunmaker obtained a patent for 15 years and in 1472 once more a patent for building mills was issued.[115] The time was ripe for a formal law of patents. In 1474 Venice promulgated such a law, a hundred and fifty years before the English Statute of Monopolies. The Venetian Senate had in

[110] G. Mandich, *Privilegi per novità industriali a Venezia*, p. 29.

[111] L.N. Cittadella, *Notizie relative a Ferrara* (Ferrara 1864), p. 479 ff., 502.

[112] Mandich, *Primi riconoscimenti*, p. 117.

[113] G. Casoni, in *Venezia e le sue lagune*, ed. G. Correr, I, part 2 (Venice 1847), p. 218.

[114] E. Birk, *Urkunden-Auszüge zur Geschichte Kaiser Friedrich des Dritten in den Jahren 1452-1467*, "Archiv f. Kunde Österr. Geschichts-Quellen" X (Vienna 1853), p. 196.

[115] Mandich, *Primi riconoscimenti*, p. 121 f., 128 f., 130, 132.

fact previously, in 1453, passed a resolution to promote invention, but this was decision in principle.[116] The law of 1474 was the first patent law, and a major step in the encouragement of technological innovation.

The Senate of Venice decided that inventors should be granted exclusive rights for their innovations for ten years, and they threatened those who imitated them with a heavy fine and the destruction of the equipment. The inventors were also entitled to cede their rights to whomever they wished, but the Venetian government retained the right to use the invention.[117] A historian of jurisprudence who made a thorough study of the development of the patent law, concluded that the Venetian law of 1474 aimed only at the protection of the inventor's right and did not seek to create any monopoly,[118] but G. Mandich maintained that the law had both purposes [119] and he was right. A study of the patents quoted in the registers of the Venetian Senate (*Senato Terra*) shows clearly that such distinctions were not made. It has also been claimed that the law was passed on the occasion of the decision to build a big new dockyard [120] and that its main purpose was to foster the invention of new hydraulic and mechanic engines necessary in the complicated conditions of the lagoon.[121] This is questionable and the Venetian Senate did not have to reckon with any strong opposition from the craft guilds. Indeed, their relative weakness made the passing of the law possible.[122]

The patent law of Venice proved to be a complete success.

[116] MANDICH, *Privilegi per novità industriali*, p. 17.

[117] The text is printed in G. MANDICH, *Le privative industriali veneziane (1450-1550)*, "Rivista di diritto commerciale" 34 (1936), p. 518.

[118] M. SILBERSTEIN, *Erfindungsschutz und merkantilistische Gewerbeprivilegien* (Winterthur 1961), p. 18.

[119] MANDICH, *Le privative*, p. 519.

[120] SILBERSTEIN, *op. cit.*, p. 22 and see p. 32 for another hypothesis for the reason of passing the law.

[121] SILBERSTEIN, *op. cit.*, p. 27 and see also p. 29.

[122] Cf. *op. cit.*, p. 28.

The registers of the Venetian Senate contain a great number of patents granted at the end of the XVth century and in the first half of the XVIth century. Most of the patents were for the construction of water-mills and windmills or for water-pumps and dredging engines.[123] The great majority of the inventors or those who proposed the introduction into Venice of inventions made elsewhere were not Venetians. Some came from other provinces of Italy and others were German, Flemish or French.[124] The conditions stipulated by the Venetian authorities which granted the patents differed-especially with regard to their duration. But the incentive was the protection of the inventor's rights, and this was considerable. Capable technicians from many countries flocked to Venice, hoping to reap the benefits of their genius, so that Venice became a major centre of technological progress thanks to the wisdom of her law-givers.

In the last quarter of the XVth century technicians from many countries lived and worked in Venice and on its territory. The gunmakers in particular are often mentioned in the registers of the Senate because of the contracts signed with them. There were people from France,[125] Brabant,[126] Germany [127] and water engineers from France [128] and Germany.[129] When negotiating a contract of employment with a highly skilled technician the government stipulated that they would teach others.[130] The Venetian authorities also promoted experiments [131] and, as in

[123] See the statistics *op. cit.*, p. 27 and see also MANDICH, *Privilegi per novità industriali*, p. 34; R. BERVEGLIERI-C. PONI, *Three centuries of Venetian patents, 1474-1796*, paper presented at the symposium "Sources for the history of technology: national comparisons" (of the Int. Cooperation in history of technology committee) (Smolenice 1982). An appendix to Mandich, *Le privative*, comprises a synopsis of the patents granted from 1475 to 1549.

[124] MANDICH, *Privilegi per novità industriali*, 1.C.

[125] Senato Terra XI, f. 131a; XIII, f. 60b.

[126] Ibid. VII, f. 186a.

[127] Ibid. IX, f. 59a.

[128] Ibid. XI, f. 86a.

[129] Ibid. XI, f. 110a XII, f. 63a.

[130] Ibid. IV, f. 145b (this contract dates from the period preceding the patent law).

[131] Ibid. IV, f. 119b. (as 1930).

earlier periods, took various measures to ensure that the high quality of industrial production, particularly of woollens, would not be impaired.[132]

The impact of the systematic encouragement of technological innovation by the Venetian government can be demonstrated by the role Venice played in the last quarter of the XVth century in the development of printing. From 1469 onwards a relatively large number of German printers came to Venice where they obtained patents for their art.[133] But Greek typographers also came to Venice and worked there.[134] The Venetian government granted all these printers monopolies for printing and selling certain books or for technical improvements and later also copyrights.[135]

Although very important for technological and industrial advance, economic policy was only one of the factors promoting it. In certain major commercial towns the great capitalists and entrepreneurs also played a decisive role in promoting technology. The enterprising merchants of Nürnberg developed the linen industry in Silesia, through the putting-out system. They drew up collective contracts with the guilds of different towns and granted the workers social security and advance payments.[136] The invention of the water driven wire-drawing bench was another case of technological advance obtained by the efforts of entrepreneurs. From 1390 mechanics of Nürnberg who produced metal wire engaged in experiments aimed at the invention of automatic machines. After 1401 they enjoyed the help of the town council and later of entrepreneurs. Sometime around the year 1410 the wire-drawing bench operated by water power was invented and thereafter metal wire became one of the famous ex-.

[132] Ibid. X, f. 14a ff.; XI, f. 50a; see further XI, f. 30a ff.; cf. supra n. 89.

[133] H.F. Brown, *The Venetian Printing Press, 1469-1800*, p. 29 ff. 50 ff.; see also R. Fulin, *Documenti per servire alla storia della tipografia veneziana* (Venice 1882), (reprint from "Archivio Veneto" 23, 1882, p. 84 ff.), p. 19; C. Castellani, *La stampa in Venezia* (Venice, 1889), p. XXXIII ff. (list of printers in Venice).

[134] Brown, *op. cit.*, p. 44.

[136] H. Aubin, *Die Anfänge der grossen schlesischen Leinenweberei*, p. 144 ff.

ports of Nürnberg.[137] The foundation of the South German cotton industry was certainly connected with the economic war that raged between the markets of Upper Germany on the one side, and Milan and Venice, on the other. But those who founded the new factories were private entrepreneurs, again great merchants who used the putting-out system.[138] The birth of the new industry was to a great extent the otucome of capital accumulation in Upper Germany.[139]

Beside the entrepreneurship of capitalists, the craftsmen and workers guilds often played an important role in the foundation of new industries. In some minor centres of the new South German cotton industry, local weavers guilds had taken the initiative and production was organised according along existing patterns.[140]

That war and military needs create novelties is a truism. Herodotus begins his work with a statement to this effect. Technological innovations were not the least amongst there.

In the XVth century, the art of warfare was a major concern of engineers,[141] and in the treatises written by the engineers of that period technology and military art occupied a prominent place. It was certainly not by chance that the first modern treatise about technology to be printed was that of Roberto Valturio concerning military art.[142] The most important progress in military techniques in this period was the invention of moveable firearms. In the well known book by Kyeser (which dates from the last decade of the XIVth century) there is a depiction of a

[137] W. von Stromer, *Innovation u. Wachstum im Spätmittelalter: die Erfindung der Drahtmühle als Stimulator*, "Technikgeschichte" 44 (1977), p. 92 ff.; cf. O.H. Döhner, *Geschichte der Eisendrahtindustrie* (Berlin 1925), p. 26, 34, 40.

[138] W. von Stromer, *Die Gründung der Baumwollindustrie in Mitteleuropa*, p. 128 ff., 138 f.

[139] *Op. cit.*, p. 144.

[140] J. Kallbrunner, *Zur Geschichte der Barchentweberei in Österreich im 15. und 16. Jahrhundert*, "VSWG" 23 (1930), p. 76 ff., 80.

[141] B. Gille, (in) M. Daumas, *A History of Technology & Innovation*, II, p. 21, 16 ff.

[142] It was printed in 1472.

gun of this kind, but moveable firearms were mentioned earlier, although it was only in the XVth century that they came into general use.[143] But the first moveable firearms, the so-called arquebuses, were so heavy that they were not very practicable. During the Hussite wars much lighter muskets were invented and thereafter became the principal firearms.[144] In the same period military experts were very much preoccupied to improve the efficiency of bullets. New hollow bullets that were filled with powder which scattered the pieces on the bursting of the ball were devised and the bomb had come into being.[145] In the first half of the XVth century Jacopo Mariano of Siena invented the modern mine for the purpose of destroying fortresses.[146] A remarkable advance of military technology which involved major progress in metallurgy came with the increased use of cast iron. From the middle of the XIVth century, pieces of artillery and bullets made of cast iron were used everywhere in France and Germany.[147] At the beginning, cast iron was produced mainly for artillery. The techniques of the bronze founders were used first in an attempt to increase the liquidity of the metal by adding tin and antimony to it. Later the pig-iron of blast-furnaces was used which could be liquified more easily, and this also facilitated the development of iron bullets.[148] The techniques for casting iron, which were probably developed in the first half of the XIVth century in the Rhineland, marked a major step forward in the technological progress of the later Middle Ages.[149] For our purposes it is important to stress that at the be-

[143] B. GILLE, *op. cit.*, p. 109.

[144] B. RATHGEN, *Das Geschütz im Mittelalter*, p. 62 ff.

[145] B. GILLE, *op. cit.*, p. 107.

[146] *Op. cit.*, p. 25.

[147] O. JOHANNSEN, *Die Quellen zur Geschichte des Eisengusses im Mittelalter und in der neueren Zeit bis zum Jahre 1530*, (in) "Archiv f. die Geschichte der Naturwissenschaften u. der Technik" III (1911/12), p. 367.

[148] O. JOHANNSEN, *Geschichte des Eisens*, 3rd ed. (Düsseldorf 1953), p. 203 f.

[149] FR. KLEMM, *A History of Western Technology* (Cambridge, Mass. 1964), p. 102.

ginning iron founderies were mainly engaged in the production of artillery pieces and it was only later, in the second half of the XVth century, that they acquired other and more peaceful purposes.[150] Military needs gave other technological innovations greater momentum. The crank-and-connecting-rod system was a major innovation of the later Middle Ages, for example, which appeared in the manuscript of Kyeser's treatise. Later a flywheel was used in order to overcome the difficulties posed by the fact that the device had two dead ends.[151]

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The data we have drawn on relates mainly to two countries, Germany and Italy, but the often contradictory opinions which we have quoted show convincingly that it is impossible to explain technological and industrial progress in the pre-industrial period as the result of any single or principal factor. The impact of economic policy upon technological advance was very great, and the formidable effects of the *tarh* system (compulsory purchase of the products of State factories or its goods by the subjects) which was in vogue in the Moslem countries is clear proof of this. But there were other factors which also played a great role. How many inventions were made by single persons who, seized by inspiration, conceived a new idea and how many innovations were made by chance! Man's mind cannot be given orders.

[150] Rathgen, *op. cit.*, p. 27 ff.; Johannsen, *Geschichte des Eisens*, p. 207.
[151] Gille, *op. cit.*, p. 42 ff.