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INNOVATIONS DIFFUSED - A RANDOM WALK IN HISTORY*

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ABSTRACT: This paper discusses several innovations and their diffusion by presenting their origin, the different paths of diffusion, the obstacles and their overcoming, the time factor involved and some other aspects. The innovations studied have been selected on the basis of three criteria: they fundamentally changed operations in their relevant area, their timing was right, and they reached a high rate of diffusion.

KEY WORDS: Innovations, Diffusion

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INNOVATIONS DIFFUSED - A RANDOM WALK IN HISTORY

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Preamble

On the 16 August 1984 the Financial Times carried an article with the title: 'Wheeling out the all-time most useful inventions'. To qualify as a classic, an invention had to satisfy three tests.

First, it must have changed fundamentally the way the world operated. Secondly, it was supposed to have appeared at the right time so that its characteristics could be exploited to their full potential. The third test concerned **diffusion**: at least one half of the world's population either used the invention or were affected by its consequences.

On that basis the FT's selection of the top ten most useful inventions were: the wheel, the compass, the mirror, the abacus, the cannon, the printed book, the electric motor, the excavator, the fertiliser and the aspirin.

No doubt, these were all very important inventions/innovations in their times, all satisfying the criteria (although some of them, such as e.g. the mirror or the cannon may surely give rise to second thoughts...). But whether these were the 'all-time most useful' - opinions will vary.

For example, in his classic work Bernal (1974) emphasises an early example of a then new way of transmitting power - that of the horse-collar; he writes that

> 'by substituting a collar, pulling on the shoulder of the horse, for a band across his breast which constricted his windpipe, the permissible tractive effort was increased fivefold'.

Coming from China, this reached Europe some time early in the eleventh century; its immediate result was that horses could take the place of oxen at the plough and acres of land unsuited to ox-ploughing could be cultivated. Its main significance, however, was that the new horse-harness very considerably contributed to the shifting of the centre of production to the countries of the Franks and Normans, in the area around the Channel, the North Sea and the Atlantic, where the heavier soil required more ploughing power.

It is likely that Bernal would have included the horse-collar into the list of the 'all-time most useful' inventions.

Introduction

The title of this paper is to be taken quite literally: it is a random walk in history.

With the exception of air and water almost everything was a novelty - an invention and then an innovation - at one point in time. Originally, there was only neutral matter in nature; it became a natural resource as and when man somehow discovered its use for his purpose; if it proved worthwhile - diffusion followed. In this sense the number of innovations is endless: to aim at completeness is futile.

Similarly futile would be to devise some system that 'marks' innovations by importance. Let us just take two examples of the FT's list: the compass and the printed book.

Admittedly, the compass made possible the epic exploratory journeys of the early seafarers and played important part - in its original and then further developed form - in the advance of shipping; but were other major innovations that directly influenced shipping not just as (if not more) important?

Again, there is no argument about the importance of Johann Gutenberg's innovation of the printing press (anno 1448); but could it have become the world's major instrument of learning and entertainment without the development of the two necessary conditions for its spread: the modern methods of printing and of papermaking? Without these two only relatively very few printed books would be around!

Thus, there cannot be an olympic race among innovations; each of the major innovations may be very important in its own field but not necessarily more important or useful than another major innovation in another sphere.

This is why the 'walk in history' that follows is intended to be - and will remain - random. The selection of the innovations discussed in brief case studies is admittedly random and arbitrary but all of them could pass the introductory (though necessarily slightly modified) 'three tests': they fundamentally changed operations in their relevant area; they came onto the scene at a time that, with the benefit of hindsight, was right; and they reached a high rate of diffusion in the sense of having been used by, or have influenced, at least one half of the relevant 'population'.

Instead of 'random walk' the title could also be 'anecdotal history' of a group of innovations and their diffusion. No great new addition to economic theory should be expected from this contribution. Nevertheless it is hoped that presenting their origin, the different paths of diffusion, the obstacles and their overcoming, the time factor involved and some other aspects - the diffusion stories will make worthwhile reading and perhaps even supply not only stimulus but also base material for further research.

Random or anecdotal - any writing is expected to be structured somehow. The brief case studies chosen will be classified into groups, loosely defined as energy, transport, materials, productive processes and equipment, and finally a miscellaneous category of 'novelties' affecting the way of life.

Energy and power

In the beginning, there was the human muscle, later supplemented by the power of domesticated animals. The harnessing of the powers of nature - the movement of air and water - was the obvious next step and its instruments were the waterwheel, the windmill and the sailing boat.

Watermills were known in the West - coming from the Orient - in the second or first century BC but they started to be more widely adopted two or three centuries later only, when slave labour grew scarce. The waterwheel was an enormous progress; one used by the Romans could grind some 400 pounds of corn an hour; archeology has unearthed traces of establishments of considerable size such as a corngrinding plant in the fourth century AD at Arles, in the south of France, equipped with 16 waterwheels and capable of grinding 7000 pounds of corn an hour (Maddox, 1975).

Their real breakthrough occurred early in the Middle Ages; by then water-mills were no longer only used for grinding grain and pressing olives (as originally) but also for other activities such as driving saws, powering fulling mills or the triphammers of forges. The Domesday Book (which took stock in 1086 of the Norman conquest) recorded 5624 water mills, on average almost two in each of the three thousand communities in England alone; by the end of the seventeenth century there were more than half a million watermills in Europe, many of them operating more than one wheel (Cipolla, 1974).

The use of watermills in cloth production accounted for an extraordinary growth in thirteenth-century England and remained important there even during the industrial revolution, running textile machinery. The tall **wind-mill** came several centuries later but its diffusion was then rapid; towards the end of the 12th century windmills had become a common feature of the landscape, their number was sufficient for the Pope to impose a tithe on them (Mokyr, 1990).

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During all these centuries the use of **wood** had been on the increase; it was the main source of fuel, the exclusive material for building ships and boats and also one of the main building materials. It was also the base material of the first processed fuel: charcoal, known already in biblical times (Bible, Proverbs 26:21).

In the then most developed areas supplies were limited: the first recorded shortage of wood occurred in the Athenian economy at the time of Pericles, in the 5th century BC (French, 1964). Rapidly developing North-Western Europe was initially rich in forests; these supplied the wood for a while - but as from the late 14th century local shortages started to develop, probably in England first.

Growing industrial and construction activity was a drain on the timber resources of England; domestic heating and cooking also depended on fuelwood and the rapid increase in shipping required growing quantities of timber. Rising imports from the Baltic and elsewhere could only ease but not solve the relative scarcity (Trevelyan, 1964). The answer to it was coal.

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There is evidence that **coal** was used by the Romans in some of their settlements in Britain more than 1500 years ago, but the earliest accounts of coal-getting operations date back to monastic records in the late 12th century in Britain (and also in Germany, at about the same time). Monks were the first to recognise and appreciate the value of coal as a substitute for fuelwood (Platt, 1968).

The earliest method of getting coal was the gathering of the 'black rock' sorted by tidal action along shores of the North East coast. As demand slowly grew coal diggings were organised by local landowners where seam out-crops permitted easy access; but local demand was small and soon an export trade developed from the port of Newcastle (since inland transport was difficult in those days) with regular shipments of 'seacoal' to London and other coastal towns as well as to the continent (as 'charbon de roche').

Fuelwood was in short supply despite several acts of Parliament aimed at the conservation of forests and in the winter 1542/3 the first fuel crisis hit London. A levy was raised on all citizens 'towards provision of seacoals from time to time to be provided and brought to this city to be kept in stock' (Platt, 1968). Nothing much came of this stockpiling plan - maybe because of limited output. There was also prejudice against coal; its growing use in London caused 'clergy and nobility to complain of danger of contagion from the stench of burning seacoal'.

Many of the sources of coal were in monastic possession; then Henry VIII dissolved the monasteries (1547), confiscated their properties and redistributed these lands to new landlords who were more enterprising and also much more in need of income. Thus, growing demand for the new fuel coincided with incentive to the producers.

Coal's advance was slow; although by 1578 'brewers, dyers, hatmakers and others' altered their furnaces to the burning of coal, the heaviest users, ironworks, invariably needed charcoal, and timber remained irreplaceable in shipbuilding and housing. Household use offered the least resistance and a strict Act in 1615 wholly prohibited the use of wood as domestic fuel (Lewis, 1973).

Coal production of course rose continually. The annual average production in the decade ending 1560 was 210 thousand tonnes, in 1681-90 3 million tonnes and a hundred years later it exceeded 10 mn tonnes a year. But, after having overcome the initial resistance, it was never enough. The break-through came early in the 18th century.

At that time coal output was principally limited by the rate at which water could be removed from the mine. It was quite common to use as many as fifty horses in relay (and at least one colliery is reported to have employed five hundred horses [EB 1974]) to raise the water, bucket by bucket or by means of special water gins, to allow production to continue. The deeper one dug, the more difficult it became to drain the infiltrating underground water from the pits.

The first attempt to change this situation was that of Savery whose steam-operated pump, constructed in 1689, was quickly followed by Newcomen's steam engine in 1705 (Hornsby, 1977). This was an enormous step: the steam engine "in an instant... put every coalfield which was considered as lost within the grasp of its owner" (Platt, 1968). Towards the end of the 18th century, Watt's greatly improved steam engine added further stimulus to the production of coal.

An equally important invention was that of Darby, the ironmaker in Coal-brookdale, Shropshire, who first replaced charcoal by coking coal in 1709. The Darbys (three Abrahams in succession), by further improving their method, had thereby created a new and large market for coal and succeeded in overcoming (at least for their own industry) the wood shortage.

Thanks to the diffusion of these two major innovations and subsequent changes in the production and use of coal, its importance increased rapidly. In the years preceding the Great War of 1914-18 British coal output in the other major producers in Europe rose equally or even more rapidly (table 1).

Table 1. Coal production in Europe, 1820-1913, Million tonnes, annual averages

	1820-24	1830-34	1850-54	1870-74	1890-94	1910-13
Great Britain	17.7	22.8	50.2	123.2	183.2	275.4
Germany	1.2	1.9	9.2	41.4	94.0	247.6
France	1.1	2.0	5.3	15.4	26.3	39.9
Austria-Hungary	0.1	0.2	1.4	9.9	27.5	50.7
Belgium	..	2.4	6.8	14.7	19.9	24.8

Source: B.R. Mitchell, European historial statistics, 1750-1950, Macmillan, London, 1975.

Coal was the source of power of the industrial revolution; it has been a very 'common' material ever since. But it was a great innovation earlier in time and had to face formidable obstacles before its diffusion could begin to really take off. The 'lead time' was very long: several centuries. To point to all this has been the aim of having gone into all the bove details .

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Petroleum is generally considered a 'modern' fuel. In fact it is older than coal. It was known to the Babylonians (2500-538 BC) from surface deposits which they used as pitch or asphalt (EB 1974); mention is made of the pitch covering Noah's ark in the Bible (Genesis 6:14) which was probably the same as the asphalt used by Babylonians: outcroppings of Mesopotamian petroleum deposits, today's wealth of the Middle East.

After a very long pause petroleum came to (still very local) prominence again when an oilwell was drilled in Modena, Italy, in 1640; at about the same time oilwells were developed in the area that was to become the Baku oilfield. The 'oil era' took off much later, and from the New World, when Colonel Drake's major commercial oilwell was brought into production in Western Pennsylvania in 1859. Its product - as well as the Baku oil - was mainly used as kerosene for lighting (and also for medical purposes, in small quantities); later on it began to be used for heating too, but oil's real take-off is a phenomenon of the 20the century.

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Natural gas was used in China around 1000 BC, for lighting, cooking and heating. The gas was escaping natural reservoirs but the Chinese are also said to have drilled deep wells to obtain gas which they transported through bamboo pipelines. Its large-scale use in the West is a relatively recent phenomenon which depended on its transportation, eventually solved in two alternative ways: by pipeline and by specially built ships delivering it in frozen form (both incorporating a number of innovations).

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Faraday is generally considered as the father of the basic invention that started off **electricity**, although he could not have presented his theory in 1831 without the outstanding previous achievements of scientists like Benjamin Franklin (1749), Galvani (1791), Volta (1800), Ampère (1822) and others. It was a very long way from Faraday's experimental work to the large-scale electricity industry that started to take shape early this century. Electricity's first use was for lighting but its adoption as a power base for industrial purposes followed soon after. (One reason why Britain was relatively lagging in the development of electricity was the strongly entrenched position of town gas for lighting).

Table 2. The production of electrical energy, Thousand million kilowatt-hours.

	1907	1913	1920	1930
Great Britain	2.7	4.8	8.5	17.7
Germany	3.2	8.0	14.5	29.1
France	0.7	1.8	5.8	16.9
Italy	0.9	2.2	4.7	10.7
Sweden	0.3	1.4	2.6	5.1

Source: as for table 1.

The pioneer of electricity was the USA; already in 1907, when Britain was still a great industrial power, much more comparable to the USA in terms of total industrial output than any time later, her electricity production was only one fifth of that in the USA; moreover, only one half of the British electricity production was used in industry whereas the same proportion in the USA was three quarters. In Europe, Germany was the leader in disseminating the new type power but its diffusion was universal (table 2).

*

Nuclear power was hailed as the answer to the energy hunger of the industrial world. The first commercial nuclear power station at Calder Hall in the UK (1956) was followed by reactor building programmes of considerable size in the majority of industrial countries. However, after a remarkably swift takeoff its diffusion was first slowed down by the trouble at Three Mile Island in the USA and then practically halted by the major disaster at Chernobyl in the Ukraine.

Whilst these two adverse events gave rise to serious ecological considerations, at about the same time the original expectations that estimated nuclear generation as the cheapest source of energy (apart from hydropower) proved to have been misconceived and major problems allied to the decommissioning of reactors remained technically - and financially - unsolved. As a combined result, most plans to build additional nuclear power stations have been shelved almost everywhere, with the exception of France which embarked early on the most grandiose scheme of 'nuclearisation' and where by now well over one half of electric power is being generated by nuclear reactors.

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The importance of the **steam engine** has already been mentioned above as enabling coal production to expand; equally if not more important has been its part played as a source of power for industry and elsewhere.

Although James Watt was the champion of this new device, he did not invent it. The first scientist who understood the power of steam and the uses of cylinder and piston was Hero of Alexandria, who invented a sort of reaction turbine in the first century AD. Newcomen's engine was widely used by

Watt's time but his further developments (the separate condenser in 1769 and the rotative engine in 1781) were very major improvements which perfected the steam engine by reducing to 8 pounds from 30 the quantity of coal needed to produce one horsepower for an hour. (Successive technical improvements, chiefly in America, relatively soon reduced this to 1 pound of coal).

The spread of the steam engine was one of the most important pre-requisites of the industrial revolution. To put it in perspective: at the peak of the waterwheel era the installed capacity in Britain was about 30.000 HP; in comparison, by 1870 the installed capacity in textile mills alone was 478.000 HP (Ray-Uhlmann, 1979). By 1880, total steam engine capacity in Britain reached 7.6 million HP and at the same time there were steam engines with a total capacity of 9.1 mn HP installed in the USA and 14.4 mn HP in the rest of Europe (Landes, 1969); thus, the diffusion of the steam engine had been fairly rapid everywhere in the then advanced countries (table 3).

Table 3. The spread of steam engines in Europe, 1840-96.
Installed capacity in millions of horsepower

	1840	1850	1870	1896
Great Britain	0.62	1.29	4.04	13.70
Germany	0.04	0.26	2.48	8.08
France	0.09	0.27	1.85	5.92
Italy	0.01	0.04	0.33	1.52
Austria-Hungary	0.02	0.10	0.80	2.52
Belgium	0.04	0.07	0.35	1.18

Source: as for table 1.

*

The steam engine's peak as the industrial power base was around the turn of the century. As from then the **electric motor** took over. The first electric motor of industrial /commercial significance was demonstrated in Vienna in 1873 by Gramme, but more important was the invention of by Tesla of the first alternating-current electric motor in 1888, the prototype of most of the electric motors in use today (EB 1974). One of the great advantages of the electric motor was that it supplied power individually to each piece of the productive equipment (for example, to each machine tool separately), something the steam engine could not offer. The diffusion of the electric motor was rapid, following with some lag the spread of electricity.

Transport

Once the steam engine had established itself as a stationary source of power it was a logical next step to put it on wheels, make it mobile, and adapt its force to transportation. Thus, the **locomotive** was born. Already in 1804, Trevithick constructed a locomotive for pulling coal wagons in Wales. Stephensons's first locomotive was functioning in 1814, yet the first rail

Table 4. European railways

(i) Railway building started					
before 1830	**1830-39**	**1840-49**	**1850-59**	**1860-69**	**1870 and later**
Britain France	Belgium Germany Italy Netherl. Austria-Hungary	Denmark Ireland Russia Spain Switzerl.	Norway Portugal Sweden	Finland Greece Bulgaria Romania	Serbia
(ii) 50 % of the longest pre-1940 rail network built in decade ending					
1870	**1880**	**1890**	**1900**	**1910**	
Belgium Britain Ireland	Austria-Hungary France Germany Netherl. Switzerl.	Italy Portugal Spain Serbia Romania	Denmark Norway Russia Sweden	Finland Greece Bulgaria	

Source: as for table 1.

transport for passengers (and not for hauling coal), the famous Stockton-Darlington line, had to wait until 1825.

Railway building became the prime mover of the national economies as from the time they embarked on it - which was different: Britain started in 1825, France, Germany and Belgium followed within ten years; then the novelty spread slowly to the east and north of Europe (table 4). It took thirty years to reach Scandinavia and forty years to reach the Balkans. It provided lasting occupation to many; it is generally considered as the main force stimulating the upturn of the second Kondratiev cycle and then helping to maintain it over thirty years (crudely: 1844-74).

The railway network - and in general, the railway era - reached its peak in the interwar years, in the 1930s, but already by 1880 one half of the longest (pre-1940) national networks were in place and operating in the West European 'core' countries: Britain, Germany, France, the Benelux countries, Switzerland and Austria-Hungary (table 4). Considering the mobilisation of the huge resources required for railway building, this means relatively rapid diffusion which continued well into the present century: more than 20 % was added to the 1920 length in quite a few West European countries, such as France, Denmark, Norway and Finland, not to speak of others like Greece, Bulgaria and the USSR.

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Another important adaptation of the steam engine revolutionised shipping: the **steamship**. The first steamships were built by the British and the Americans very early in the 19th century. In Rotterdam, the future Europort, the first steamship appeared in 1823. Until then the sailing ship exclusively ruled the waves, but it had changed almost beyond recognition over the centuries: it was a very long way from the ancient sailing ship (usually helped by the muscle of rowing slaves) of the ancient Greeks and Romans to the fast 'clippers' of the middle decades of the 19th century.

Just two comments, worthy of interest, of the development of the sailing ship. The first indicates how 'law and order' can play a part in technological advance: the elimination of piracy in earlier centuries made it possible to dispense with the carrying of heavy metal deck-guns on merchant ships. This change, rapidly spreading among shipbuilders, not only vastly increased the freight-carrying capacity of ships but improved the safety of their design by lowering the centre of gravity (Johnson, 1975).

The second additional remark goes back to the 17th century, when Holland was the chief entrepôt and trading centre of Europe, the focal point of continental Europe's maritime transport and commerce. She was also one of the leading shipbuilding country. "The Dutch ship of the period was standardised; as many as one a day could be built in the yards of Saandam, which used laboursaving machinery" and - partly as a consequence - the Dutch ships' freight rates were one third to one half lower than those of any rival (Kindleberger, 1978).

Competition between the sailing ship and the steamship was intense. The latter had of course been further improved and developed but it took over hundred years before sailing ships practically disappeared from the merchant navies of the leading countries. Table 5 and the technical notes included there indicate the fierce competition, as well as the progress of the steamship in a self-explanatory manner.

It was around 1890 that steam accounted for one half of the merchant fleet of the USA and it was about the same time that the then new propulsion system, the motor ship, started. By around 1940, the peak of the steam era, over 90 % of US merchant ships were driven by steam, not more than a small fraction, maybe 1 % by sail and the rest were motor ships whose share continued to rise rapidly (Grübler, 1990).

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We turn now to **shipbuilding**, not so much as a case of some particularly outstanding innovation, rather to illustrate the penetration of a newcomer into the fairly exclusive camp of the major industrial powers: Japan.

In earlier times Britain was the leading country in shipbuilding; as late as 1951 she produced more than one third (by tonnage) of the world's new ships. By 1972, one half of the world's ships, in tonnage terms, was made in Japan; the British share fell to 5 %. How did the Japanese achieve this?

The 'cheap labour' argument was not valid any more: by 1973 wages, including social charges, were 29 % higher in Japanese than in British

Table 5. Substitution of steam for sail in shipping, 1810-1960

Year	New ships built (% in total) a		Technical changes influencing substitution during decade ending in year shown
	steam	sail	
1810	b	p 100	First open-ocean steamboat: 1809
1820	2	98	First Atlantic crossing by steamboat
1830	5	95	-
1840 c	10	90	(First successful screw-propelled ship (First Atlantic crossing primarily using steam
1850 c	15	85	-
1860 c	16	84	First screw-propelled and first iron ship to cross Atlantic
1870	31	69	-
1880	33	67	First steamship able to beat 24-hour speed of clipper ships
1890	47	53	(First all-steel ship (First steamship able to beat top speed of (clipper ships
1900	60	40	US warship 'Maine' built with full set of sails
1910	74	26	(First ship without any sails (First ship with steam turbine
1920	91	9	First very large turbine ships with steam
1930	94	6	-
1940	98	2	-
1950	99 1/2	1/2	-
1960	p100	b	-

Source: Bright, 1978.

(a) Approximate and rounded.
(b) Less than 1/2 %.
(c) The peak of the clipper ship era: 1840-1865.
(p) p100 = practically 100 %.

shipbuilding. The price of steel, the most important single material in shipbuilding, had been consistently higher in Japan than in Britain (Ray, 1976). And yet, for many types of ships Japanese prices were generally lower than British, German or Swedish prices, although Japanese shipbuilders did not have subsidies or credit facilities on a scale very different from those elsewhere.

The cause of their success lies elsewhere. Management attitudes, technology, R&D and subsequent innovation, marketing methods and organisation - in the combination of these factors is the answer.

The Japanese were the first to recognise the importance of the market for tanker ships and correctly foresaw its forthcoming spectacular growth. They specialised in the building of tanker ships, though not entirely neglecting other types either.

Table 6. The growth of tanker ships, 1935-1973

Year	Largest tanker		Transport cost c
	dwt a	draught b	
1935	12	27 1/2	..
1943	17 d	30	..
1950	28	34	1.27
1955	46	40	1.14
1960	115	50	0.88
1965	130	51 1/2	0.68
1966	210	58	0.57
1970	327	81	0.80*
1971	367	89	0.77*
1973	476	92 1/2	0.69*

(a) Deadweight, 1000 tons.
(b) Approximate, feet.
(c) Approximate transportation charge, Persian Gulf to US East coast ports; US dollar per barrel; current costs in 1935-66, 1972 dollars from 1970 onwards (marked by an*).
(d) This was the T-2, a standard oil tanker used during World War II, with a capacity of 17.000 dwt.

Source: as for table 5.

The times when the Japanese were mere imitators - and they were very good in that role too - had been passed: Japanese shipbuilders introduced many significant innovations in naval architecture, in the engineering of the ships and of the shipbuilding process affecting the construction, the size, the handling and the manning of the vessels. These made the construction cheaper for them, and the operation of the ship more economic for the shipowner.

The Japanese advance in shipbuilding was primarily due to a long list of innovations on the technical side, forcefully backed by managerial/organisational innovations. Table 6 shows the growth of the size of tanker ships over time and also the simultaneous reduction of the transportation costs of oil. From about 1960 onward the growth of the ships' size was chiefly due to Japanese shipbuilders.

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The idea of the internal combustion engine goes back to the late 17th century but not before the last quarter of the 19th century was it adopted to create a horseless carriage that was to become the omnipresent symbol of our days: the **automobile**. Daimler and others constructed their first cars in the late 1880s, France produced 500 cars by 1893. By about 1910 motor car production passed the one million mark in the US; the leading figure of the industry was Henry Ford (who was the most important car-maker in Britain too, producing there around 1910 more cars than the next two largest firms combined).

Henry Ford brought the automobile to the masses by introducing the assembly line to the motor industry. Thereby he created a new method of managing the mass production of goods and reduced production costs to an extent which created mass demand for a product that earlier was beyond the reach of anyone but the rich. He recognised (or re-discovered) two important things: that cars had to be much cheaper if they were made and sold in quantity, and that in order to achieve this some other method of making them had to be devised.

The solution of the second problem came to him first: while witnessing the system in the Sears-Roebuck mail order warehouse in Chicago where low-paid clerks assembled orders by picking items from the shelves. Starting from this experience he developed a system which converted the automobile from an individually constructed machine into one that was assembled, using prefabricated and conveniently stored parts and components (Levitt, 1976).

Ford's Model T, the 'Tin Lizzie', was the first low-priced car to combine speeds of up to 45 mph (=72 km/h) with mechanical reliability. It remained in production for 19 years during which time a total of 15 million were sold.

By leaving it mechanically unchanged for so long and by other managerial schemes (such as gaining control of sources of base materials and of distribution) Ford was able to reduce the original price of $850 to $260 by 1923 (Harpur, 1982). The T-Ford was available in a selection of colours until 1914, when the production line was moving so fast that only black paint could dry with the requisite speed. (The saying that one could have a T-Ford in 'any colour as long as it was black' was more than a joke). The rapid diffusion of the automobile was to a large extent due to Ford's largely managerial innovations.

Automobile technology has of course changed since Ford's time. Grübler (1990) uses the demonstration of some of these changes - notably, the diffusion of selected recent innovations: automatic transmission, power steering, air conditioning, disc brakes, radial tyres and electronic ignition - for supporting his theory: the convergence tendency of the diffusion of incremental innovations when approaching the end of the diffusion life cycle (what he calls the 'season of saturations') within an innovation cluster such as automotive technology. Chart 1, taken from Grübler's work, also indicates the considerable shortening of the time period from introduction to saturation: the later an invention became an innovation - in this particular example - the sooner it seems to have approached saturation.

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The market for **motorcycles** has also shown interesting developments in the postwar years. As far as natural endowments go, no country had any great advantage over the others. Yet, during the 1950s the earlier chief producers were beaten by the Italians. Chiefly because of the situation on their home market they were the first to recognise the need for smaller and cheaper products. They started to mass-produce scooters and flooded the European market. Some 10-15 years later, however, they had to face formidable Japanese competition.

Honda, the main Japanese producer, only started to make small motorcycles in 1954. In those days, driving licences for small (50 ccm) motorcycles were not required in Japan and the tax on them was very low. In view of rising incomes, the market potential was enormous. The size of the engine, however, had to be retained.

Honda set out with the aim of powerfully raising performance. He did not change any of the basic principles but developed everything: new alloys for the cylinder, a new valve mechanism and an original ignition and carburettor system, in order to double the revolutions per minute and the compression ratio. Without any major technological breakthrough but by means of a chain of minor developments, better design and the resulting improved performance Honda created and outstanding motorcycle, backed by large-scale production and marketing his product soon became a market leader not only in Japan but elsewhere too (Ibuka, 1969).

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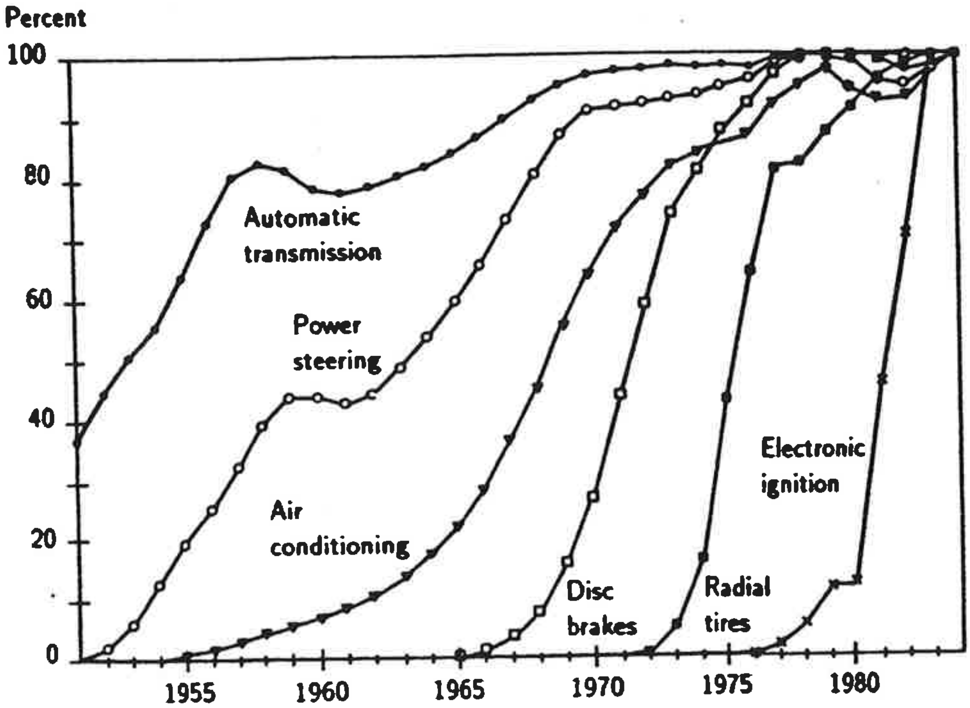
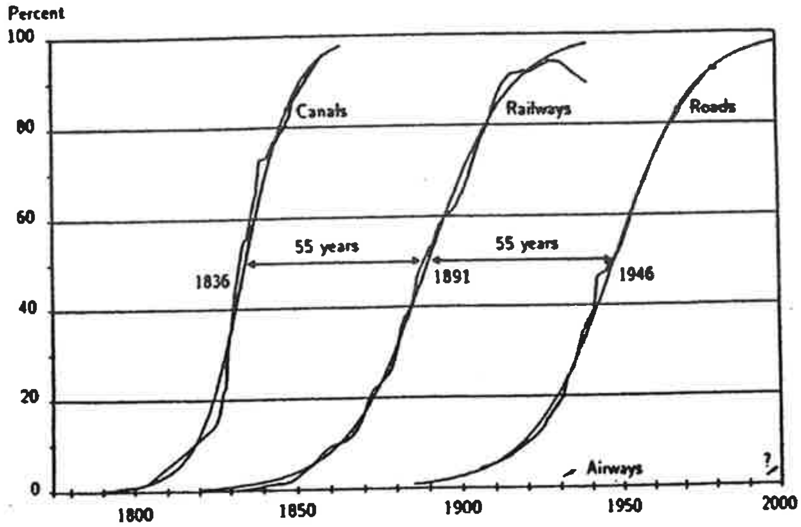
Grübler's study (1990) is a mine of information concerning technological change and diffusion in transport. Chart 2 is reproduced here (with the author's permission), showing the historical development of major transport systems - notably canals, railroads and surfaced roads - in the United States.

Chart 1. Diffusion of new technologies in the US car industry, Per cent of output



Source: Grübler, 1990.

Chart 2. Transport infrastructures in the USA: growth and diffusion



Source: Grübler, 1990.

The chart compares the actual diffusion over time of each of the three systems in terms of the percentage of a theoretical/practical limit (which is supposed to represent 100 % saturation; absolute saturation levels are of course different between the three infrastructure systems). The estimated logistic curves are also added. His comments to this chart are as follows (p. 187):

> "The development of canals, relative to the saturation level, was much quicker than the expansion of railways and surfaced roads. The time it takes to grow from 10 to 90 per cent of maximum network size is about 30 years for canals, 55 years for railroads and 65 years for surfaces roads. The midpoints between the individual infrastructure growth pulses (i.e. the time of their maximum growth rate) are spaced 55 years, as are their periods of saturation.
>
> It is remarkable that the saturation and the onset of decline of all three infrastructures coincides with prolonged economic recessions (i.e. in the 1870s, 1930s and 1980s). At the same time these periods of structural discontinuity see the emergence of new transport systems: surfaced roads around 1870 and air transport in the 1930s."

Industrial materials

Apart from coal and iron, the material of outstandly great importance in the decades of the industrial revolution and even after was **cotton.** Its chequered history goes back to ancient times.

There had been a cotton industry for a very long time in India. Its products became familiar to the Greeks through the advance of Alexander the Great (323 BC); later on, Malta produced some cotton for Rome but the Indian products remained prized for their quality and whiteness (Singer, 1959). The Moslems introduced cotton production to the Middle East and from there into Spain; they also greatly improved the quality of cotton products. By the end of the Middle Ages, in the parts of the old world south of the 40th parallel (crudely: a line between Madrid and Ankara) cotton had become the main raw material of clothing and other fabrics (Mokyr, 1990). With the decline of Islamic culture, however, the cultivation of cotton fell into decay, certainly on the 'liberated' European areas.

As a result, until rather late in the 18th century cotton fabrics were considered a luxury, carrying a high price. Their imports to Europe - and also to Britain - grew and in 1700 the vested interests of the British wool and silk industries took measures to prohibit importation of Indian cottons. Lancashire alone was exempt from that ban - and this is one reason for the location of the cotton industry there (Fay, 1948).

The development of the British (then almost exclusively Lancashire) cotton industry was crudely parallel with the spread of cotton cultivation in the southern North-American colonies - but it was slow. In the decade ending 1790 British cotton consumption was not more than 8.000 tons a year. From the early years of the 19th century, however, it took off very rapidly, rising from small beginnings to over 100.000 tons by 1830 and to an enormous average 870.000 tons in the years before the Great War. Britain had remained the leading cotton producer for a long time: until as late as around 1890 the raw cotton consumption of Britain was more (and in earlier decades of the 19th century much more) than the cotton use of all other European countries together (table 7).

Table 7. Raw cotton consumption, Thousand tonnes a

	1781-90	1825-34	1855-64	1885-94	1905-13
Great Britain	8.1	105.6	369.4	691.8	868.8
France	4.0	33.5	74.1	127.0	231.1
Germany	-	3.9	42.0	208.2	435.4
Austria-Hungary	-	6.8	32.7	96.9	191.4
Italy	-	-	1.8	73.2	186.0
Belgium	-	0.1	10.9	25.3	83.3
Sweden	0.3	0.3	5.1	12.7	20.4

Source: as for table 1.

(a)Annual averages for the periods shown.

The enormous rise of cotton and its phenomenal diffusion was due to a number of factors. First, its supply was plentiful; only during the 'cotton famine' caused by the American civil war in the 1860s, was there any scarcity lasting a few years.

Secondly, cotton's superior properties made it attractive to both producers and consumers: it took dyes well, laundered easily, ventilated very well (i.e. was pleasant to wear) and its fibres lent themselves easier to mechanisation compared to its main competitors, linen or wool.

Thirdly, technical progress in the cotton industry was rapid: a feverish inventive wave focused on the manufacturing of cotton, starting in the second half of the 18th century, affecting all stages of the cotton trade. It resulted in the constant shifts of bottlenecks as individual, partial processes were improved from the separation of fibre and seed to the weaving and finishing of the final fabric. All this development was packed into a few decades before and after the turn of the century. The territorial concentration of the industry (in Britain) made the relatively rapid diffusion of innovations fairly easy.

Apart from the ascent of the British (mainly Lancastrian) cotton industry and some allied areas - e.g. the engineering industry serving the cotton mills or Liverpool as the main cotton port and commercial centre - cotton's social impact was considerable in that it made clothing much cheaper than garments made of other materials such as wool, linen, silk or leather and thereby greatly contributed to the rising welfare of the poorer classes.

But again, the early part of cotton's history apart, it took many decades of technological progress, the diffusion of many innovations in many directions, before cotton had become a widely used material.

*

After cotton, the rather obvious stop in our random walk is the case of **man-made fibres.** Their importance is best reflected by their high share in the world's textile fibre consumption which for some recent time has been moving around 50 %.

The two main categories of man-made fibres are: cellulosic fibres (which are 'regenerated' fibres, usually wood-based cellulose made into a slurry from which the fibrous material is extracted) and synthetic fibres (usually produced from petroleum derivatives as polyamide, polyester, acrylic and similar resins).

The very first cellulosic fibre was produced in France towards the end of the last century as nitrocellulose fibre; it was a failure and was discontinued because of high flammability. The two main forms of cellulosic fibre (viscose and cuprammonium) had been invented in the last century but their commercial development followed later. At first they were considered artificial silk; only since 1920 have they been known by the generic name of rayon.

The next step was the development of nylon at Du Pont in the USA, in the 1930s, overtaking by some years perlon, the rather similar German fibre (Jewkes, 1969; Höllscher, 1972). The manufacture of these from long-chain polyamides was the basis of further research which eventually resulted in the whole family of synthetics including elastomeric fibres which came onto the market in the late 1950s. Their main advantage as compared with natural fibres is their resistance to wear and tear; in many applications they are equal or superior to natural fibres but in others less so (unless mixed with them).

Their high share in the total fibre consumption clearly demonstrates their fairly rapid diffusion. This was due not only to those properties which made them more suited than natural fibres in certain applications but also to their competitive price. Otherwise the rapid spread of man-made fibres would have been difficult to achieve because at the time of their development and initial marketing there was no particularly notable shortage of textile fabrics made of conventional, natural materials.

(Indeed the case of man-made fibres are often treated as an example of 'science/technology push', as distinct to 'market pull', for the above reason. This is questionable. Whilst no shortage of cotton or wool exercised any 'market pull' for a new textile material, the key research work was done by the R&D organisations of leading enterprises - such as Du Pont, ICI, IG Farben, etc. - presumably with a fairly clear general idea of the potential of the new fibre, in case of success. Apparently, they recognised at the time - what Rosenberg (1976) formulated later - that "potential demand may exist for almost anything under the sun".

*

In contrast to man-made fibres, the rapid development and subsequent diffusion of **synthetic rubber** was due to wartime scarcity. Indeed, this was one of the most notable among the many advances in the area of materials during the 1939-45 World War, althoug its history dates further back.

The synthesis of rubber had been in the forefront of scientific interest for some time, mainly because of the high price of natural rubber. Between 1900 and 1914 some 500 patents were taken out for the manufacture of elastomers from various base materials, most of them in Germany or Britain (Haber, 1971).

Synthetic rubber production had actually started in Germany during the 1914-18 Great War; at its peak it covered about one tenth of German domestic demand in 1917-18. The 'Ersatz' product was, however, of poor quality with no hope of competing against natural rubber. With the higher production and the lower relative price of natural rubber in the interwar years R&D on synthetic rubber was at a low ebb. German efforts were stepped up again during the 1930s, eventually resulting in 'Buna', a fairly successful substitute for the natural products; it covered almost all German requirements during World War. The real revival, however, came from the USA.

Two major companies championed R&D in the USA in the 1930s: Du Pont was aiming at high-price premium products with specific qualities superior to that of natural rubber and started marketing 'neoprene' in the mid-1930s; Esso was making butyl rubber for inner tubes from 1937. The experience gained was vital later when - cut off from the usual source of supply by the Japanese invasion of South-East Asia - a major industry was very quickly built up.

After the small experimental output of about 3.000 tons in 1944, production reached 94.000 tons only four years later (Höllscher, 1972). This is an illustration of the potential rapidity with which technology responds to pressing shortages when backed by powerful enough support.

According to FAO estimates, in 1988/9 synthetic rubber accounted for 74 % of the total elastomer consumption of the developed countries; estimates for the total world consumption indicate that all through the 1980s about 70 % was synthetic and 30 % natural rubber. This high rate of the diffusion was not only due to the existence of the new material but also to a long list of incremental improvements/innovations. This development is a characteristic of the general direction of the potential of new, man-made materials, experienced in other areas as well, such as e.g. in the cases of man-made fibres or plastics.

In the beginning the main objective is the replacement of the (in the case of rubber, scarce) natural product. Once this is achieved, further development and improvement takes place; these produce specialised varieties. The first batches of the new material may even be somewhat inferior to the natural product as an all-purpose substitute, but the later more sophisticated varieties may serve specific purposes better than, or just as well as the original. This can be demonstrated by the very wide range of the application of synthetic rubber.

*

The first successful material among those belonging to the by now large family of **plastics** was bakelite. Its inventor, the Belgian Baekeland (working in America) started in 1904 to search for a synthetic substitute for camphor, whose price rose suddenly. He was not successful and turned to experimenting with the production of synthetic shellac (Reuben and Burstall, 1975). The eventual result of his work - as a typical example of serendipity - was a hard, chemically resistant plastic which has come to be called bakelite. He patented his three-stage reaction process in 1909. Bakelite was not only of importance itself but opened the way that led eventually to today's rich array of plastic materials and synthetic resins.

The two most widely used among them are polyethylene and polyvynilchloride (PVC). Low-density polyethylene was commercialised by ICI in 1939, the high-density variety was a product of the 1950s; the two types are made by different processes and have different properties, but both have found innumerable uses.

PVC provides an example of how long the development of a novel material can take. Vynilchloride was first prepared in 1835 but a method of polynumerisation was not found until around 1930. The large-scale manufacture of PVC did not start until the late 1950s when oil-derived ethylene replaced the earlier, much more expensive base material, acetylene.

Plastic materials are now being made with greatly varying properties, including transparent polymers. They replace many conventional materials such as wood, paper, metals, glass etc. competing even with those that are in abundant supply. (Of course it can be argued that the abundance is the result of the existence of a synthetic substitute.) The degree of diffusion can best be characterised by the large world output of plastics which reached towards the end of the 1970s 50 million tonnes, at the time when world production of aluminium amounted to about 13 mn tonnes.

*

Aluminium was first isolated in 1825 by Orsted but for a very long time it remained an extremely expensive metal, without any major industrial or commercial importance.

At the Paris Exposition in 1855 one bar of 'silver from clay' (the 'clay' found in France at Les Baux, which gave bauxite its name) was exhibited next to the crown jewels. It was considered a pecious metal for jewellery, it was expensive and its use was restricted to royalty and the uppermost class: cutlery made from the new metal appeared at court banquets, aluminium rattle for a baby in the French imperial family and an aluminium watch charm worn by the King of Siam are mentioned as examples (Wallace, 1937).

Having attached great hopes to the military use of the new metal, Napoleon III granted a liberal sum for research aimed at the perfection of its manufacture, but it was not before 1886 that a successful process of electrolytic reduction was discovered (independently but simultaneously by Hall in the USA and Heroult in France).

This was the beginning of the aluminium industry - in principle but not yet in practice. Processors did not know how to apply the new material, what to use it for. Manufacturers of the new metal had an uphill fight; the recognition of its qualities eventually established stable demand - but this took several decades. As from there, the diffusion of the new metal was rapid and its use received extra stimulus after the 1973 oil shock when energy conservation and the coinciding tendency for lighter and smaller products made aluminium a particularly favoured metal. In 1976-87 in the seven largest OECD countries aluminium consumption, related to industrial production, rose by 12 % whilst the use of other major non-ferrous metals fell markedly (Ray, 1991).

*

Papermaking was invented around 600 AD in the Far East. In Europe the chief base materials were rags, all kinds of textile fabrics and residues (in the Far East these were supplemented by other fibrous materials, such as bamboo and barks). However, in the 19th century the supply of rags proved insufficient to feed the papermills which were under pressure from rising demand, particularly in Europe. This led to the use of wood for papermaking.

In 1840 a patent was granted in Germany for grinding wood into pulp for manufacturing paper. The first groundwood paper is recorded as having been produced as early as 1841 in Halifax, England. In the 1850s, paper was already being made from chemical woodpulp, produced first by the 'soda', and a few years later by the sulphite process.

Woodpulp has quickly become the base material for papermaking. In some areas deficient in forests other, locally available cellulosic materials are also used, such as straw, esparto, bagasse (the residue from the crushing of sugarcane), bamboo and some textile fibres but their total quantity is small. Rag paper is still being made, in relatively tiny quantities, for special high quality requirements, for example banknotes, life insurance policies, Bible paper, etc. (EB 1974, Landes, 1969).

The rise in incomes, growth of population, reduction of illiteracy and other factors raised demand to an extent which again required that the 'new' source, woodpulp, should be supplemented. The rising price of paper has started to give signals of exploitation outrunning the growth of relatively easily accessible forests, especially in Europe. These have been the reasons stimulating various forms of paper recovery. Re-use of waste paper obviously reduces the need for virgin fibre.

Earlier, recycled paper could only be used for coarse papers, boxboards, etc. but newer processes - especially de-inking - now make it possible to produce good quality white papers if the waste input is of good enough quality.

*

Dyes of natural origin have been used from time immemorial; dyeing was a specialised trade even in biblical times (Acts 16:14). With rapid industrial advance, demand for dyes had been growing fast and although no evidence can be found in the records of any serious shortage, by the middle of the 19th century it must have been fairly obvious that requirements would shortly outstrip the then available natural supplies.

The search for synthetics began in the middle of that century and in 1856 Perkin, a young English chemist, was the first to produce a synthetic aniline dye, 'mauveine'. Its manufacturing started within two years. He continued working on alizarine dyes and found a solution but was beaten by the German firm BASF applying for a patent, based on German work, one day before him. (Freeman, 1974).

The determination of the structure of natural dyes and synthesising them paved the way for many other synthetic dyestuffs. Noteworthy among them was Bayer's synthetic indigo discovered in 1880, which contributed significantly to the German domination of the synthetic dye industry early this century (Haber, 1971). Diffusion of the use of synthetic dyes was extremely rapid (at the cost, of course, of the earlier suppliers of natural dyes, among them the Indian indigo trade).

As a slight digression it deserves mention that it was the dyestuff industry which gave first rise to the industrial research laboratory. This new institution emerged just at the right time, after the theory of organic chemistry had just reached a point where it could help the chemist to find out structures and make new compounds - at about the middle of the last century. (Before then it was largely an empirical field.) This was an important development from the point of view of further advance in the chemical field. The later great pharmaceutical and polymer industries also originated from attempts to apply the same approaches as had been successful with dyes.

*

It has already been mentioned in connection with aluminium that the diffusion of a new material may take a long time. Two other examples to prove the point are those of tungsten and titanium.

Although scientifically known since the end of the 18th century, commercial production of **tungsten**, and its use in industry, did not start until 1900 (Li and Wang, 1955). Its first use was for lamp filament but the then new metal found other markets and has become one of the important strategic metals, especially for making high-speed and other special steels.

Titanium has also long been known but its refining and applicability remained unsolved until 1936, when a reduction process was developed in Germany. Commercial production started after the war. Its penetration in the aircraft industry has been rapid, thanks to its high strength/weight ratio (Jewkes, 1969). It accounted for only 2 % of the airframe structure weight of the Trident I and the Boeing 727, but for as much as 9 % of the more recent Boeing 747 (the 'Jumbo').

There are also cases pointing to the contrary: relatively rapid acceptance and diffusion of new (mostly synthetic) materials.

Diamonds for industrial use were in short supply during the interwar years. Synthetic polycrystalline diamonds had been developed and they are now perfectly competitive with the rare natural stone in many of the rapidly growing industrial applications. (USBM, 1978, National Geographic, 1979).

It was during the search for a substitute for diamonds that **tungsten carbide** was developed in the interwar period; it is a versatile and extremely tough material, an alternative to the natural mineral with superior properties, extensively used in the engineering industries in applications where high resistance to wear and tear is expected (Jewkes, 1969).

The growth industry 'par excellence' of recent decades has been electronics; it requires **quartz crystals** in particular grades and increasing quantities. Natural resources in the required quality are limited. As an alternative, synthetic quartz crystal has been developed and widely accepted as a substitute of comparable quality (USBM, 1978).

Radium was discovered by Pierre and Marie Curie in 1898; by 1910, the metal was isolated and demand for various (mainly medical) uses has been growing ever since. Man-made radio-isotopes are now replacing the scarce natural radium in many cases (EB, 1974).

*

We close this section - which could be continued at great length - by surveying, in a sketchy manner, the development of **building materials**, restricting ourselves to British practices. For hundreds of years, until the last century, timber, stone and bricks had been the traditional building materials. Early in the last century, iron framing began to be used occasionally for buildings where a wide span was required; the Crystal Palace erected in Hyde Park to house the 1851 Great Exhibition was the most spectacular example of this form of construction.

In 1824 artificial cement was first made in England on the Thames-side at Northfleet and when, some sixty years later, the technique of reinforcing concrete with iron-rods (ferroconcrete) was evolved, new styles and designs of building became possible. (Concrete was essentially a plastic material which made it possible to get away from rigid straight lines.)

Another development of the last years of the previous century was the rolled steel joist. Steel-framed buildings can dwarf the largest constructed with traditional materials. It is the technological development of ferro-concrete and the application of various forms of steel that has made possible the huge factory buildings, the skyscrapers for offices and high-rise blocks of flats, that had rapidly become a normal part of the urban landscape. (Whether or not to the advantage of humanity or ecology - this is another question...)

Productive processes and equipment

This section will be brief because Chapter 7 is discussing the diffusion of selected technologies in Finnish industry. In that chapter the diffusion of **some major postwar innovations** is described and analysed; although the discussion is concentrated there on Finland, here we will give an overall view of their diffusion.

Among the eleven major new technologies

- three would not pass the '50 % test' - that is, although they have been spreading rapidly, it could not yet be said that one half of the relevant population has adopted them; these are the relatively new 'high-tech' equipments/processes: numerically controlled machine tools, industrial robots and flexible/automatic manufacturing systems;

- one has been overtaken by the events: the then new platecutting methods in shipbuilding have been replaced by the computer;

- one was a process not requiring any major additional equipment (gibberellic acid in malting/brewing) and, also for other reason, not really relevant here;

- one, nuclear electricity, has been discussed earlier in this chapter;

and to the remaining five we return below.

None of these five new processes that could be introduced without new equipment; the diffusion of the process assumes the previous or simultaneous diffusion of the equipment that makes the adoption of the new process possible. This, indeed, is the case with many process or equipment innovations: more often than not, the two cannot be separated. Therefore, the diffusion of the process is generally the same as the diffusion of the appropriate equipment and vice versa.

Table 8. The diffusion rate of selected major 'new' industrial processes/equipment, 1989

Process/equipment	The West	USSR	Eastern Europe a	Note
1 Basic oxygen steel-making	95+ b	47	65	Includes electric steel; in % of crude steel output
2 Continuous casting of steel	90+ c	17	21	In % of crude steel output
3 Tunnel kilns in brickmaking	90+ d	e	65 f	In % of total brick output
4 Float glass	90+ b	e	g	In % of all flat glass output
5 Shuttleless looms in cotton-type weaving	56 c	65 h	32	In % of total loom stock

Source: G.F. Ray, Innovation and productivity in Eeastern Europe - an international comparison. National Institute of Economic and Social Research, Research Reports No 2, London, 1991.

(a) Includes Bulgaria, Czechoslovakia, Hungary, Poland, Romania and East Germany. (b) OECD. (c) EC-12. (d) France, Germany and Italy. (e) Not available. (f) Without Romania and East Germany. (g) Czechoslovakia alone has adopted this process in Eastern Europe by 1989; there 85 % of plate glass and 27 % of window glass was made by the float process. (h) Comparability of these looms uncertain.

The basic oxygen process is unimaginable without the converter, float glass making without the float line, the continuous casting of steel without the continuous casting machine, and so forth. These, together with tunnel kilns in brickmaking and shuttleless looms in cotton-type weaving (both self-explanatory) are the 'remaining five' processes.

Their diffusion in Finland and elsewhere is discussed in some detail in chapter 7 and therefore a summary treatment will suffice here. This is presented in table 8 which shows the diffusion rates of these five technologies in the West (i.e. in some geographical category representing 'the West'), in the USSR and in the countries which used to be called Eastern Europe, characterised by Soviet-type central planning.

Each of these five new technologies - the process and the productive equipment - had become dominant well before the year 1989 (for example, the diffusion rate shown for the West was reached some ten years earlier); the year 1989 has been chosen in order to indicate the most recent position in the USSR and in Eastern Europe, where the adoption of these once novel techniques appears to be lagging.

The first four technologies listed in table 8 have reached saturation; the fifth, shuttleless looms, did not yet. This difference does not mean that the latter is less progressive in its own line than the others; its explanation leads us to the concept of the divisibility of the investment incorporating the new technology.

The first four technologies cannot be adopted without the building of a major new plant. The equipment incorporating these technologies is usually of large capacity, often large enough to make the older technique wholly redundant. For the plant (sometimes for the whole company) in question this is often 'either - or', either sticking to the traditional method or converting to the new; there is hardly any graduality. To build a new plant of any of these types requires major capital investment; when built, the new plant takes over huge quantities of output from the earlier technology in large, indivisible chunks. Thus, diffusion is swift.

(On the national level the gradual nature of the diffusion remains, reflecting the sum total of the decisions taken by many individual establishments/companies.)

Shuttleless looms (and others, such as e.g. numerically controlled machine tools) are in a different class. They too represent successful new technologies but can be adopted piecemeal, within the existing plant, even on a trial basis, at relatively moderate cost. Their installation does not exclude the possibility of retaining a good deal of the old machinery (e.g. automatic shuttle looms) in the reserve or even in continual operation. Their diffusion therefore takes a course different from the above large, indivisible systems. It is not all or nothing - rather it is gradual adoption.

*

For the illustration of the importance of diffusion of novel processes we turn to a case that lacks glamour: **fats.** For specific periods the more advanced areas of Europe were bedevilled by the shortage of fats. The first severe scarcity arose in the middle part of the 19th century. By then ever growing quantities of soap and candles were required as a consequence of the rising standards of living of the steeply increasing population. The traditional base material of soap and candle making was solid animal fat, which was needed in similarly growing quantities for food as well.

When a shortage of animal fats developed they were supplemented by vegetable oils. These were acceptable in the kitchen but not in industry where hard, and not liquid, fats were needed. Liquid fats of both marine and vegetable origin were available in adequate supply but the problem of how to harden them remained unsolved for a long time.

It was eventually solved by hydrogenation, a process developed by Normann, a German chemist, in the first decade of this century (Jewkes, 1969). This invention rapidly transformed the soap and allied industries and freed them from material supply troubles. There was only one condition: to secure the plentiful supply of vegetable oils.

Although agricultural developments are largely outside the scope of this writing, this seems a convenient place to point to the important role of agronomists, plant breeders and other scientists who contributed not only to the enormous increase in oilseed production, but also to the plants' resistance to disease, through pest control.

Genetic manipulations raised the oil content of some plant varieties (such as the sunflower seed, whose oil content was raised from 28 to 50 per cent) and developed almost entirely new breeds. One example of the latter is the safflower in the USA, in which the normal proportion of acids was totally reversed so that the oleic acid content increased from the normal 12 per cent to 80 per cent (EB 1974).

*

Papermaking materials have been discussed in the earlier sections but the development and diffusion of **papermaking machinery** may also deserve attention.

Prior to the invention of the paper machine, paper was made one sheet at a time by dipping a frame or mold with a screen into a vat of stock. Lifting the frame allowed the water to drain, leaving the sheet on the screen. The sheet was then pressed and dried, but its size was limited by the size of the frame that a man could lift from the vat of stock.

In 1798, Robert, a Frenchman, constructed a moving screen belt that would receive a continuous flow of stock and deliver an unbroken sheet of wet paper to a pair of squeeze rolls. This machine, although patented in France, did not become a practical reality until a much improved version was built in the plant of Henry and Sealy Fourdrinier in England. This was in 1807 (EB 1974). They too patented their machine. Two years later a cylinder paper machine was devised by John Dickinson, also in England. These were the crude beginnings of the modern papermaking machinery.

The bulk of papermaking nowadays is based on the Fourdrinier machine whose diffusion had been relatively rapid and worldwide. Whilst the original idea and the basic operations have remained the same to this day, many incremental innovations and engineering changes have converted the initially much simpler machine into the giant and sophisticated version that may be found in the main papermaking plants.

According to table 10 in chapter 7, in 1986 the average capacity of Finnish paper plants, equipped with several paper machines, was 216.000 tonnes/ year. A plant of this size requires the repeated movement of huge quantities of material; therefore the mechanization (perhaps even automation) of materials-handling equipment has been and continues to be an important aspect of the development of papermaking. Innovations in that area have been just as significant as the improvements of the papermachine itself - and their dissemination has been just as rapid.

*

The industry most closely allied to papermaking is **printing.** Since Gutenberg's great invention in the 15th century, the printing press and the whole printing trade has changed very radically and several times. It would exceed our scope here to go into great details and we restrict ourselves to just a few innovations of this century.

It was around the turn of the century that printing underwent a radical transformation when Lanston's monotype typecasting machine (invented around 1896) became to be widely used. This made it possible to set type mechanically in single characters; the type then could be melted down (composing and casting were separate) and recast again.

Around 1904 offset lithography for printing on paper became commercially viable. Rubel in the USA designed a printing press capable of transferring the image to be printed from the litho stone to a rubber rolled which came in contact with the paper.

Large display type, invaluable to the daily press but also for other purposes, was available by about 1906 thanks to Ludlow's new kind of typesetting machine, developed in the USA. In the same year, colour printing arrived for general-interest books, cards etc. New and cheap techniques allowed colour printing using only three hues (cyan, magenta and yellow) instead of the wide range of colours previously needed.

To speed up production and add more pages The Times of London installed in 1908 monotype composing machines. (It might not have been the very first but it was the first recorded installation of this kind.)

The range of colour printing was further extended in 1926 by the introduction of aniline dyes which allowed, by means of flexible rubber plates, printing on a variety of surfaces including plastics, fabrics and any kind of rough paper. Aniline (called flexographic) printing became very important in the packaging industry, especially in food packaging because these dyes were less toxic than those used earlier.

In 1947 the first - still rather primitive - scanning print system was introduced; the original picture was electronically scanned by a photocell, this transmitted signals to a cutting head which engraved a reserved copy of the illustration on the printing surface.

Towards the end of the 1960s computer-controlled composing systems penetrated the printing trade. These consisted of a single computer serving many keyboard inputs. Composers, once the aristocrats of the newspaper trade, had been made redundant. Diffusion was swift: by 1970, a total of 1200 companies worldwide used one of the computerised composing systems. (Harpur, 1982.)

These were just the highlights of the development of the printing trade. The diffusion of each of these novelties had been rapid among the large and medium-sized printing houses but not necessarily among the small printers. (The number of small printers is large but their output accounts for a relatively minor share of printing output.)

*

Finally, a Nordic example. One of the bases of the expansion of Swedish engineering industry was an early (1870) invention, the **milk separator**. This innovation greatly contributed to the creation of an exporting dairy industry in the Nordic countries, apart from its important role in helping engineering to become established. Its diffusion was fairly rapid.

The country that benefited perhaps most of the Swedish milk separator was Denmark. The new equipment provided a changed technical basis for dairy farming, an important part of the Danish economy, and contributed to a considerable extent to the development of the cooperative movement in Denmark. (The latter, in turn, was instrumental in transforming the export of pigs into the sale of packed pork, another innovation resulting in the significant growth of another important part of Danish agriculture.)

*

The way of life

In this final section only a few of the 'novelties' will be mentioned that were major innovations at one earlier point of time and have by now become part of the normal way of life of the average citizen of Western (and, to an extent, also of Eastern) countries. Their list is endless; as before, it is imperative to be selective and the selection has been arbitrary.

Let us begin with the **household**. In the 1851 Census of Population for Scotland alone there were 115.000 persons classified as domestic servants. This was the second most common occupation. By 1911, their number had risen to 133.000. But by 1951 they had practically disappeared (it was 4.000) - and not in Scotland alone: in most countries of the West. Household work, however, continued to be done. It is now being done by a whole host of electrical and other domestic appliances, supplemented by detergents and other household chemicals and by a long list of convenience goods. All must have been invented and innovated some time, somewhere. Their worldwide diffusion is obvious: they are omnipresent.

*

One of the recent additions to the housewife's 'armoury' is the **microwave oven**. The first microwave cooker, still in more primitive experimental form, went on sale in the late 1940s in the USA. It was a spin-off from the development of radar, using the same principle (Harpur, 1982). The domestic varieties started to be sold in the 1960s in America and a few years later in Europe; they had been quickly installed by the catering trade and then by ordinary households.

Outside the kitchen perhaps the most useful helper of the housewife is the **vacuum cleaner**. Its predecessor (still in use) was the carpet sweeper invented by M. Bissell, a china shop owner in Michigan (who put it together because he suffered from headaches caused by an allergy to the dusty straw used for packing his wares). The first lightweight vacuum cleaner was constructed in 1907 by M. Spangler in the USA; he sold the rights to W. Hoover who introduced the first commercial model in 1908. It had become so popular that 'hoovering' found its way into the dictionary.

*

Most businessmen and professional persons carry along a ballpoint pen, a pocket calculator, an electronic/quartz watch and (at least one) credit card. None of these were around before the war. Their worldwide diffusion is beyond doubt.

The **ballpoint pen**, nicknamed after its inventor, was devised in 1938 by a Hungarian journalist, L. Biro, because he was bored with always blotting his manuscript; it became very popular in the 1950s.

*

The **pocket calculator**, this most popular witness of electronic advance, was further developed in the early 1970s when the first programmable versions started to come onto the market; no larger than a man's hand, these could be programmed to solve scientific, engineering and statistical problems. At their peak, in the second half of the 1970s, world production of pocket calculators exceeded 50 million a year (Harpur, 1982).

*

The **electronic/quartz watch** was developed around 1960 at the central laboratory of the Swiss watch industry. A small quantity was made by them but the Swiss watchmakers, enjoying at the time booming demand for their traditional products, did not recognise the significance of the innovation. Instead, the Japanese became interested, started producing it in large quantities and within a few years took over from the Swiss as the world's leading watchmakers. The electronic/quartz watch, whether in digital form or retaining its earlier 'face', very quickly achieved worldwide acceptance.

*

The first **credit card** was issued by Diners' Club in 1950 (Harpur, 1982); it heralled the 'cashless' society: soon major banks, travel organisations, department stores, airlines, gasoline/petrol stations and other followed.

*

Another, much older, financial innovation was the system of **hire purchase.** It is believed that it was pioneered (at least in Britain) in Victorian times by the Singer Sewing Machine Company (Harwick, 1971) though it came in its own after the Great War of 1914-18 when many working men began to earn somewhat more than was needed for just sheer necessities, leaving a small margin for 'luxuries'. It created a new social trend, the full consequences took some time to appear, but now, largely (though not exclusively) thanks to hire purchase, working people are as deeply financially committed through their HP borrowing as the middle class has almost always been.

*

According to UN statistics, in 1988 there were 62 **telephones** in use per 100 inhabitants in Finland. (The same number was 82 in Denmark and 86 in Switzerland.) This great popularity of the most widespread means of communication directs the attention to the development of **telephone exchanges**. In the beginning, they were hand-operated. These primitive exchanges had been replaced by mechanical exchanges, named 'Strowger', after their inventor. As an oddity it is worth telling the story of this invention.

Towards the end of the 19th century there were two undertakers in Kansas City; one of them was a Mr. Almon Strowger. His rival's wife was an operator on the local telephone exchange, who consistently diverted Mr. Strowger's calls - and hence his business - to her husband. To overcome this handicap, Strowger developed the basic design of the mechanical telephone exchange which has come to be named after him. His switching system was controlled automatically by a dial instead of a human operator. The Bell Telephone company was quick to latch on to the idea and install Strowger-type exchanges across the USA. The first exchange of this kind in Europe was installed in Munich, in 1909 (Harpur, 1982; FT, 1985). There are much more modern exchanges nowadays but Strowger exchanges have still been widely used in the 1980s and will remain in operation until the last will have been replaced by automatic ones.

*

A more recent innovation in communication is the **fax machine**. Whether or not it has already reached the 50 % diffusion rate is difficult to tell because of the uncertainty of defining the 'relevant' population. Certainly, its use in business circles has spread rapidly but recently more and more adoptions have occurred in areas that are 'non-business' or strictly private. In any case, the diffusion of the 'fax' has been very rapid, considering that it was reported as late as in 1980 that "a document can now be sent from London to Toronto in minutes with Intelpost, the first public international electronic facsimile service" (Harpur, 1982).

*

The newest addition to the array of home entertainment appliances is the video. It was during the 1970s that the **video** had been transformed from a specialised branch of communication technology to a mass domestic market. In the late 1970s it was a luxury item, ten years later it was a commonplace. By the end of 1987 there were 45 million video cassette recorders (VCRs) in use in the USA and 24 million in Japan. In Britain, 51 % of all homes had altogether 10.6 mn VCRs in June 1988; the number of homes using a VCR doubled from 1984 to 1988 (PSI, 1989).

*

In today's way of life it is almost impososible to avoid the use of **escalators**. Although invented before the turn of the century, the first of these moving staircases was introduced in 1911 by the London Underground, at Earls Court station. The public was vary: a main with a wooden leg was employed to ride up and down the twin escalators (which were only 40 ft = 12 m long) to demonstrate their safety (Harpur, 1982). Modernized versions, with additional safety features, developed by Elisha Otis, started to be installed from about 1921 onward in US railroad stations and department stores.

*

As compared with the past, better **health** is one characteristic of today's life, thanks to advances in medical science and in the pharmaceutical industry as well as to the diffusion of the method of treatment and the drugs developed by them. Here only a handful of those pharmaceutical innovations will be discussed which have become disseminated worldwide, saving many lives. (This is not to belittle the enormous importance of new medical appliances such as, for example, the kidney machine or the various types of scanners.)

Aspirin is related to a chemical found in the bark of the willow tree; it had been used to relieve pain for centuries, for example by Napoleon's troops. Its manufacture was started in Germany by Bayer in the last decade of the 19th century (Haber, 1971). The more acceptable soluble form of aspirin, developed by an English firm, came onto the market in the 1950s. **Insulin**, the saviour of those suffering from the previously often fatal diabetes, was introduced in the 1920s, made from animal pancreas gland extracts (Jewkes, 1969).

A new generation of wonder drugs was ushered in with the introduction of the first **sulpha drugs** in the 1930s. Soon they were to be eclipsed by the more potent antibacterial agents, the **antibiotics**. Penicillin, the first of the antibiotics, was discovered almost by chance by Fleming in 1928, but its vast potential as an antiseptic and antibiotic began to be exploited only after the development of its manufacture in the early 1940s. The 'natural' penicillin, however, had its limitations: in the beginning it had to be injected and it was without effect on certain bacilli. Research into the nature of its chemical structure and considerable further development resulted, some fifteen years later, first in semi-synthetic penicillin (with more profound effects) and later on the large and still growing family of newer antibiotics (EB 1974, Jewkes, 1969).

The effect of the diffusion of new drugs and advanced medical practices can be demonstrated by the number of lives saved. Just two examples:

- In 1940, about 30.000 persons died of tuberculosis in England and Wales alone. In the mid-1970s this figure was around 1.000; by now it is even lower.

- Around 1870, of every one million children (under 15 years old) about 5600 died of four diseases: scarlet fever, diphteria, whooping cough and measles. Table 9 shows the gradual reduction of the number of deaths until - thanks to new types of vaccination and other medication - these killers had been practically eradicated in the early postwar years.

Table 9. Deaths per million children [a] from four diseases

Period [b]	Scarlet fever	Diphteria	Whooping cough	Measles
1870	2258	871	1405	1109
1880	1575	709	1349	988
1890	572	781	1163	1234
1900	331	872	1003	1184
1910	224	491	756	874
1920	84	439	473	675
1930	48	294	360	357
1939	27	287	183	149
1949	3	30	81	47
1959	0	0	6	8
1969	0	0	2	6

Source: Office of Health Economics, London; Which, January 1977.

(a) Under 15 years old.
(b) Five-year periods ending in year shown; annual averages.

Concluding thoughts

The discovery of the penicillin might have been an event of scientific interest but without its innovative manufacture and widespread use - in other words: its diffusion - it would have remained without practical importance. Precisely this has been the case with each to the innovations listed - visited in the course of our 'random walk'.

The innovation/diffusion case studies concern 'novelties' of very different nature. Some can absorb many millions of investment capital, others (e.g. videos) may be obtained for a few hundred dollars. Comparison among them may be meaningless. And yet, it is difficult to escape the impression, however superficial, that the period for possibly complete diffusion - or the time from innovation to general (even if not 100 %) acceptance - has shortened over time.

This can best be demonstrated on the example of industrial innovations: their dissemination nowadays still takes quite a long time - two or three decades - but this is no more than a fraction, crudely one third, of the time it took in the last century or early this century. (E.g. 100 years for the steam engine, 60-100 years for the railways but 25-30 years for oxygen steel, 20-25 years for float glass, 15-20 years for numerically controlled machine tools.) This aspect has been discussed more thoroughly elsewhere (Ray, 1990) and we can conveniently finish our random walk by quoting the last sentence of that study: "Many factors contributed to this acceleration, among them the more open and more closely intertwined nature of the world economy, but beyond any doubt the rapid development of the exchange of information must have played a decisive part."

London, September 1991

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