# ECN230 SRP session 16. Economies of Scale, Technology & Productivity

## ECONOMIES OF SCALE

Henry Ford launched his Model T in 1908, turning the car from a luxury into a mass-manufactured product. Ford's original factory used standardized parts and fitted them into vehicles as they travelled along a moving assembly line. By 1914 this cut the labour time needed to assemble a Model T from 12.5 hours to 93 minutes. Before long the factory complex became the centre of a vertically integrated empire, designed to produce everything required to make a car [1].

The Model T, however, soon became obsolete. The weakness of the Ford system was exposed: it is extremely expensive and slow to switch a giant factory from one product to another. Ford halted production, laying off 60,000 workers. After six months 15,000 machine tools had been replaced and 25,000 others rebuilt, so that the factory was ready to make the new Model A. As the switch from Model T to Model A plunged Ford into loss, Alfred P. Sloan, president of General Motors, presciently observed that carmakers would need to "adopt the 'laws' of Paris dressmakers". That meant bringing out new models more often [1].

The shortening of product cycles and the fickle nature of modern markets has duly seen manufacturing atomise into small, nimbler, more specialist factories. The original Ford factory lives on with just 6,000 workings making pick-up trucks [1].

Some see offshoring to low-wage countries, particularly in Asia, as the mega-factory's last hurrah. Yet long supply chains and distant plants are leaving producers vulnerable to rapid changes in their home markets, so production has been trickling back. Meanwhile, new materials and manufacturing methods, such as 3D printing, are demolishing the economics of scale that giant factories have relied on [1].

Economies of scale (EOS) run out at a certain point and the largest US firms may be beyond it. Some things only get bigger. Boats, planes, skyscrapers and shopping malls all have size records, which are routinely broken. Companies are operating at record scale, too. The trend towards growing ever larger is clear, whereas the economics of bigness are far murkier [2].

Container ships provide a good example of EOS. Greater size in container ships promises greater efficiency, as fixed costs are spread over higher output. Introduced in the late 1950s, the first ships could carry 480 20-foot equivalent (TEU) containers. By 2006 the biggest shifted 15,000 TEUs. Cost factors explain the rise: transport adds nothing to the final value of a good so cost minimisation is all-important. As shipping costs per container kept falling as ship sizes rose, container ships kept growing. A new range of 18,000 TEU ships was launched in 2013, the most efficient [2].

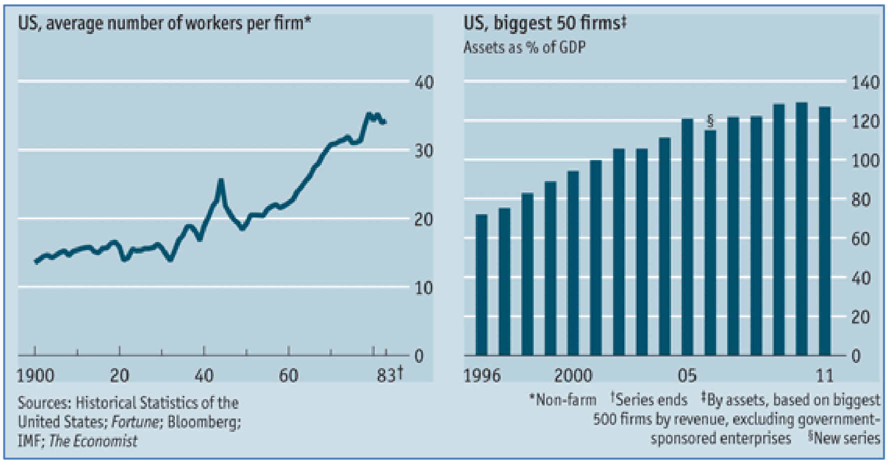
In buildings, however, the gains from scale may be running out. It is possible to exhaust the savings that come with size. Between 1931 and 2007 the record for the world's tallest building rose from 381 to 828 metres. As buildings get taller, the fixed cost of land per square metre of office space falls. Other height-related changes offset this saving. The wind force on a building rises exponentially with height, making design more complex and costly. Steve Watts and Neal Kalita of Davis Langdon, a consultancy, show that construction costs per square metre rise as a building gets taller.[1] In addition, the useable space per extra floor starts to fall as the central "core" of the building gets bigger. Most very tall buildings are at an inefficient scale, propelled skyward for reasons of prestige rather than efficiency. If developers focused on cost alone, they would opt for clusters of mid-rise buildings [2].

Where do firms lie on this spectrum? Firms have gotten bigger and the long-run trend tends toward bigger firms. A snapshot of the US economy shows huge dispersion in firm size: around a third of US workers are employed by one of the 6m small firms (fewer than 100 workers) with another third employed by one of the 980 large firms (more than 10,000 workers). Robert Lucas[2], U. of Chicago, documented how the average US firm size increased over a 70-year period (see left-hand chart) [2].

The world's biggest firms get bigger because (1) a firm gradually outdoes its rivals, or (2) more suddenly through mergers and acquisitions (M&A). M&A are important in explaining gigantism. Since 1990, the assets of the top 50 US firms rose from around 70% of US GDP to about 130% (right-hand chart). All top ten US firms were involved in at least one large M&A since the 1980s [2].

Do firms making boats or buildings seek out EOS, or are they too big to be efficient? One way to answer this question is to estimate how output levels influence the costs of production in a competitive industry. The "cost function", as it is known, can be tricky to establish because firms often have multiple inputs and outputs. Take farming[3]. Estimating a cost function requires complex information on how each farm's outputs (milk, meat and crops) and inputs (labour, energy, feed, capital) interact [2].

Once the cost function is pinned down, it can be used to identify EOS. A fall in average costs as a firm's size grows bigger suggests EOS exist for firms of that size. Results vary by industry. US dairy farms, for example, have gotten bigger but there are still EOS to exploit, especially among farms with fewer than 200 cattle. By contrast, rail-industry studies[4] show dwindling EOS over time as firms grow. Overall, estimated cost functions suggest the limits of scale may have been reached for some very large firms [2].




[1] Watts, S. & N. Kalita, "Tall buildings, a strategic design guide" and "The economics of high rise", Davis Langdon Tall Buildings Research.
[2] Lucas, RE, "On the size distribution of business firms", *Bell J. of Econ*, 1978.
[3] Mosheim, R & C Lovell, "Scale economies and inefficiency of US dairy farms, *Amer. J. of Ag. Econ*., 91(3), Aug 2009.
[4] Pels, E & P Rietveld, "Rail cost functions & scale elasticities: a meta-analysis", 2003.

M&A studies support this.[5] The “winner’s curse” describes the phenomenon of M&A destroying value for the shareholders of the firm taken over. McKinsey, a consultancy, finds that: close to two-thirds of managers overestimate the EOS a merger will deliver, inflating the benefits by more than 25%. Size can even drive costs up, if firms get too big to manage efficiently [2].

If size does not drive down costs, why do big firms keep expanding? One possibility is that they seek to boost profits not by driving down costs but by raising prices. Buying up rivals softens competition and enables firms to charge more. US antitrust regulators looked at past health-care M&As, and found that prices rose significantly after some deals. Another view is that M&A are driven by something other than profit. The “empire-building” theory holds that managers are out to increase the scale of their business whatever the cost in terms of creeping inefficiencies [2].

State safety nets can distort incentives, too. The three leading US car manufacturers grew through M&A: each of them employs over 50,000 workers, and the government balked at letting them fail during the crisis. Some firms may be growing not to lower costs but to receive the comfort of implicit state support. A Federal Reserve paper (2011) supported this conclusion, suggesting banks pay a premium for M&A if the tie-up gives them “too-big-to-fail” status. None of these reasons for operating at a vast size is benign. Antitrust authorities should be much more sceptical about M&As that claim to be justified because of EOS [2].

### Global competition weakens benefits of clusters

Opened in 1845, the Cantoni cotton mill in Castellanza in Italy was the country's biggest, but debt in 1985 forced its closure, bringing down with it a large cluster of producers. In Como, 20 miles (32km) north-east, a cluster of silk firms is ailing, as is a woollens cluster around Biella, 50 miles west, victims of low-cost competition [3].

Michael Porter from Harvard Business School argued that clusters help productivity, boost innovation and encourage new firms. Porter studied how firms' geographical proximity, their close competition with each other and the growth of specialised suppliers and production networks around them make a winning combination. Globalisation, however, makes this far less certain. More open trade and improved transport links mean that bunching together in a cluster no longer offers a strong defence against cheaper foreign rivals. As Italy's medium-sized industrial firms adapt to the threat from China, the benefit from being bunched together in a cluster seems to be weakening [3].

More than 100 clusters speckle the boot of Italy: tiles in Sassuolo, food machinery in Parma, sofas in Matera, footwear in Fermo and clothing in Treviso, to name some. Some owe their existence to local natural assets—e.g., marble is quarried in the mountains behind Carrara, others are the result of skills built up over successive generations. The packaging-machinery firms around Bologna grew out of the region's tradition of precision engineering, and around Belluno, where the first ever spectacles factory was built in 1878, is still home to a cluster of eyewear makers [3].

One cluster features the world’s largest center for working brass, comprising 380 firms that together employ about 10,000 people making valves and taps and another 19,000 who work in small satellite firms involved in parts of the production process. Founded in 1951, Giacomini is a giant of the cluster with 850 employees who make brass valves, connectors and manifolds. However, quality certification, precision production and a catalogue of 6,000 products will not safeguard its future. “Germans saw us in the 1950s and 1960s as we now see Chinese products—low quality, low cost. The firm diversified into electronic controls and heating and air conditioning systems in the 1990s, a move away from its traditional business and the links to its cluster - increasingly less relevant to its future [3].

Zucchetti, a tapmaker in Gozzano, changed strategy. It bought a maker of luxury baths and basins, and shifted production upmarket, with smaller production runs and a larger product range. Zucchetti’s future performance depends less on being in the cluster than designing smart products and defending its brand. Competition is forcing firms to innovate, improve quality and build brands [3].

A jewellery cluster in Valenza hopes to protect its business by creating a group trademark and through peer pressure to keep skills in the cluster. Bruno Guarona, chairman of the jewellers' association, moans about unfair competition from China, where labour regulations are lax and firms enjoy tariffs and duties that undercut those his members face. He accuses jewellers from Valenza who have moved production abroad, as “traitors who have committed a crime” [3].

Fragmentation of production and outsourcing abroad, clear signs that firms have become less competitive, weaken the networks on which clusters are built and may even destroy their competitive advantage, warns Rodolfo Helg, an economics professor at the university in Castellanza, which occupies the buildings that were once the town's large cotton mill. He believes successful clusters in the future will be very different from those of the past [3].

In several industries within china, the clustering of similar firms in the same place created a critical mass of good suppliers and workers with relevant skills. In 2016, niche one-product towns in China produced 63% of the world’s shoes, 70% of its spectacles and 90% of its energy-saving lamps. China made 2.9 million bras, 60% of the world’s total, according to Frost and Sullivan, a consultancy. Gurao, a town in the southern province of Guangdong that together with sever other towns make China the world’s largest lingerie producer, produced some 350m bras and 430m vests and pairs of knickers a year for sale at home and abroad. Underwear accounted for 80% of the town’s industrial output [4].

During the past three decades of rapid economic growth, one-industry towns like Gurao and Chendian sprang up along china’s eastern seaboard, often in what were once paddyfields. With investment from Hong Kong and Taiwan, and a huge influx of migrant labour from China’s interior, they fuelled the country’s export boom. In 2016, there were more than 500 such towns, making products such as buttons, ties, plastic shoes, car tyres, toys, Christamas decorations and toilets (see map, clusters) [4].

Officials in Gurao insist that the town can overcome its difficulties by upgrading its technology and using machines instead of people. But attractive the capital and skill to transform Gurao is becoming more difficult. Even China’s largest underwear manufactur4ers had always found it hard to get long-term commitments from buyers. That made them reluctant to spend on research or technology. Some factories in Gurao are upgrading, for example, by making seamless laser-cut underwear and using new, more

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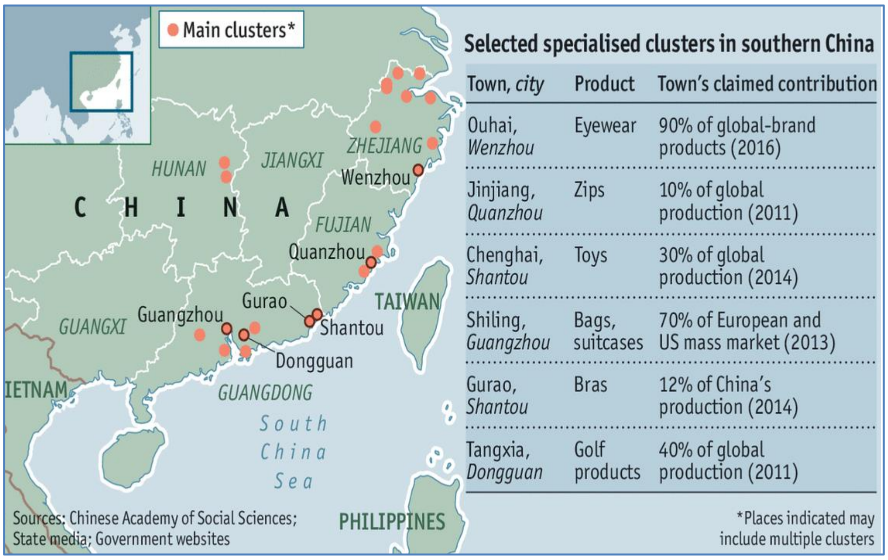
[5] “Where mergers go wrong” McKinsey Quarterly, 2004.
Thaler, RH, “Anomalies: The winner’s curse” , *J. of Econ Perspectives*, 2(1), 1988

comfortable, materials to underwire bras, but most remain low-tech and labour-intensive [4].




Some of the one-product boomtowns could fade away, Leaving little behind but the concrete shells of employ factories and polluted soil. Gurao and other such places have generated extraordinary wealth in once dire-poor parts of the country. But to thrive in the future, they will need to look beyond the bare necessities [4].

https//www.economist.com/news/china/21697004-one-product-towns-fuelled-chinas-export-boom-many-are-now-trouble-bleak-times-bra-town
Video on one-product cluster towns in China (3.42 min)

**Third industrial revolution is digitising manufacturing and transforming the way goods are made**

The first industrial revolution began in the UK in the late 18th century, with the mechanisation of the textile industry. Tasks previously done by hand in hundreds of weavers' cottages were consolidated into a single cotton mill, and the factory was born. The second industrial revolution came in the early 20th century, when Henry Ford mastered the moving assembly line, ushering in mass production. These revolutions made people richer and more urban [5].

Old-style manufacturing involved taking many parts and screwing or welding them together. The factory of the past was based on cranking out zillions of identical products, making possible economies of scale which changed the economy—and society—in ways unimaginable at the time [5][6]. Ford famously said that car-buyers could have any colour they liked, as long as it was black [5].

A third revolution set off by advances in computing and information and communication technology (ICT) in the late 20th century, promises to deliver a mixture of social stress and economic transformation [5]. This change, making manufacturing go digital, is driven by a number of remarkable converging technologies: clever software, novel materials, more dexterous robots, machine intelligence, new processes, notably 3-dimensional (3D) printing, and a whole range of web-based services. These technologies are capable of delivering many innovations, e.g., unmanned vehicles; pilotless drones; machines that can instantly translate hundreds of languages; mobile technology that eliminates the distance between doctor and patient, teacher and student. Whether the digital revolution will bring mass job creation to make up for its mass job destruction remains to be seen [5][6].

Powerful, ubiquitous computing was made possible by the development of the integrated circuit in the 1950s. Under a rough rule of thumb known as Moore's law (after Gordon Moore, one of the founders of Intel, a chipmaker), the number of transistors that could be squeezed onto a chip has doubled every two years or so. This exponential growth resulted in ever smaller, better and cheaper electronic devices (today's smartphones carry vastly more processing power than the supercomputers of the 1960s). Though Moore's law has approached its end (because transistors are so small that shrinking them further is likely to push up their cost rather than reduce it), commercially available computing power continues to get cheaper. Google and Amazon are slashing the price of cloud computing to customers, and firms are getting better at making use of that computing power [5].

At the same time, hardware (from processors to cameras to sensors) continues to get better, smaller and cheaper, opening up opportunities for drones, robots and wearable computers. Innovation spills into new areas: in finance, for example, crypto-currencies like Bitcoin hint at new payment technologies, and in education the development of new and more effective online offerings may upend the business of higher education [5].

History suggests that society's adjustment to the changes will be slow and difficult. At the turn of the 20th century, writers conjured up visions of a dazzling technological future even as some large, rich economies were limping through a period of disappointing growth in output and productivity. As a new age of globalisation is hailed, then as now, political systems struggle to accommodate the demands of growing numbers of dissatisfied workers. Slow GDP growth rates at the start of the 21st century is testing governments beset by new demands for intervention, regulation and support [5].

The technology under this third revolution reverses the process of the earlier revolutions in manufacturing, i.e., making it as cheap to create single items as it does to mass produce them, thereby undermining EOS [5][6]. Future factories can focus on mass customisation. The cost of producing smaller batches of a wider variety, with products tailored precisely to each customer's need, is falling. The cost of setting up a 3D printing machine is becoming the same whether it makes one thing or as many things as can fit inside the machine [5].

It works like this. First, a blueprint of the design of an objected is uploaded onto a computer and its shape and colour is tinkered with using some software. The file is sent to a 3D printing machine, which builds a solid object gradually, either by depositing material from a nozzle, or selectively solidifying a thin layer of plastic or metal dust using tiny drops of glue or a tightly focused beam. A products is built by successively adding layers of material, one layer at a time, i.e., additive manufacturing [7].

Additive manufacturing has several cost advantages over the conventional manufacturing. First, it does not require a factory or even a large space (small items can be made by a machine the size of a desktop printer). Second, there are no production or assembly lines. Third, the 3D printer can run unattended. Forth, it reduces waste by requiring as little as one-tenth of the amount of material. Fifth, it allows the creation of parts in shapes that are too complex for a traditional factory using conventional techniques to achieve, resulting in new, much more efficient designs in aircraft wings or heat exchangers, for example; and enables the production of a single item quickly and cheaply—and then another one after the design has been refined. Hearing aids and high-tech parts of military jets are being printed in customised shapes [5][7].

Additive manufacturing is only one of many new breakthroughs shaping the factory of the future, and conventional production equipment is becoming smarter and more flexible, too. New production strategies standardize the parameters of certain components required to produce a final good. This enables a (car) manufacturer to produce all its differentiated products (e.g., an engine for cars) on the same production line. Eventually it should allow its factories in the US, Europe and China to produce locally whatever vehicle each market requires [8].

Before, 3D printers were used only for prototyping, mainly in the aerospace, medical and automotive industries. Once a design was finalised, a production line would be set up and parts would be manufactured and assembled using conventional methods. Now, finished items themselves are produced by 3D printers. Because each item is created individually, rather than from a single mould, each can be made slightly differently at almost no extra cost. Mass production gives way to mass customisation for all kinds of products [7].

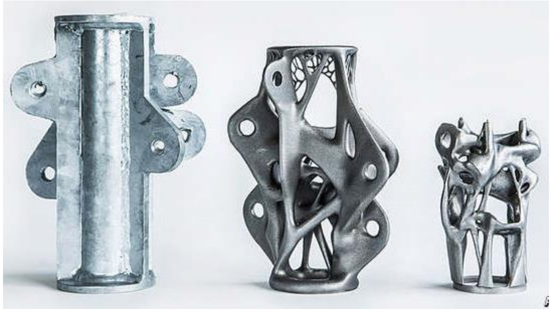
By reducing the barriers to entry for manufacturing, 3D printing should also promote innovation. If a shape can be designed on a computer, it can be turned into an object to see if there is a market for it. More can be printed, modifying the design using feedback from early users. This is a boon to inventors and start-ups, because trying out new products is less risky and expensive. Just as open-source programmers collaborate by sharing software code, engineers are already starting to collaborate on open-source designs for objects and hardware [7].

The materials used to make things are changing as well [6]. Earlier, the 3D printing process was possible only with certain materials (plastics, resins and metals) and with a precision of around a tenth of a millimeter [7]. New materials are lighter, stronger and more durable than the old ones. Carbon-fibre composites, for instance, are replacing steel and aluminium in products ranging from mountain bikes to areoplanes [5]. The large-scale use of carbon fibre began in aerospace. Both Airbus and Boeing aircraft use it extensively instead of aluminium. Not only is it lighter (about half the weight and just as strong as steel), there is also a big manufacturing advantage: large sections, like the main area of a wing, can be made in one go rather than being riveted together from lots of individual components [9].

**Software that produces the most efficient shape for components**

Manufacturing revolves around components of all shapes and sizes, but some are starting to look surprisingly different. The three widgets pictured below illustrate that transformation. They all perform the same job, but the two on the right were re-designed by a combination of software and 3D printing.

The component on the left, about a metre tall, was designed as one of 1,600 parts holding support cables and arms for a giant outdoor lighting system. It was made from stainless steel in the traditional manner by cutting and drilling sections and welding them together. The work was time-consuming and labor intensive because each of the 1,200 brackets had to be different.



The other two components were computer-analysed to find the optimal design able to provide the same strength with the least amount of material. The middle component was optimised keeping the fixing points for the arms and cables the same, and resulted in a 40% weight saving. Moreover, it was printed in one go and design variations were automatically handled by the software. The third version was obtained by allowing the system to completely rejig the entire structure. It produced a 75% weight saving.

Optimisation software typically comes up with natural-looking shapes that seem to mimic nature—which is not surprising as nature has had a few million years' head start designing structures like bones, stems and leaves. Optimised 3D-printed components could be widely used in civil engineering to save weight and materials, provided contractors and standards authorities accept them.

That is happening. Stratasys, a US producer of 3D printers, said recently that Airbus used one of its machines to make more than 1,000 parts, typically for interior use, for the first A350 XWB airliner. Stratasys said the parts, printed in a resin-type material, met aerospace certification standards. Besides being lighter, it helped Airbus meet its delivery commitments too. GE says only 3D printing will be able to make the fuel nozzles for its next generation of jet engines. Instead of being constructed from 18 individual parts, they will be printed as single items. Besides providing enhanced performance, the nozzles will be 25% lighter and should last five times longer [10].

Increasingly, new techniques let engineers shape objects at a tiny (nanotechnology) scale. Nanotechnology is already used to engineer some products with enhanced features, such as bandages that help heal cuts, engines that run more efficiently and crockery that cleans more easily [11].

Boston's biotechnology cluster consists of pharmaceutical firms, big and small, attracted in large part by the research carried out in the region's hospitals and universities. In the biological sciences the development of manufacturing capabilities is closely linked to that of the product, says Phillip Sharp, a Nobel prize-winner and co-founder of what is now called Biogen Idec, a Massachusetts-based biotechnology firm with annual revenues of $5 billion. What currently excites the industry, says Mr Sharp, is nanotechnology, taking its name from the word for a billionth of a metre. When materials are measured at the nanoscale they often have unique properties, some of which can be used in beneficial ways [11].

Nanotechnology makes it possible to manufacture, on a tiny scale, new therapeutic substances carrying information on their surfaces that can be used to direct them to particular cells in the body. The drugs delivered by such substances could be valuable in treating diseases like cancer. They are being made in small quantities now, says

Mr Sharp; the challenge will be to scale up those processes once clinical trials are completed. And that, too, he adds, will depend on both product and manufacturing innovation working together [11].

Making drugs for the most part remains an old-fashioned batch-manufacturing process. This involves assembling ingredients, often from different countries, processing them in a chemical plant into a batch of drug substance, then turning that substance into pills, liquids or creams in another factory, which might be in yet another country. All this involves a lot of moving around of drums and containers, and plenty of inventory sitting idle. It is time-consuming and expensive [11].

In a laboratory in Cambridge, Massachusetts, another way of making drugs is being developed. Raw materials are put into one end of a machine full of tubes, cogs, belts and electronics, and pills pop out of the other end. This pilot production line, a joint venture between MIT and Novartis, a giant Swiss-based drugs company, is pioneering a continuous manufacturing process for the pharmaceuticals industry. It is producing a copy of a standard Novartis drug, although not for use yet because the system is still five to ten years away from commercial operation. It relies on a combination of chemistry and engineering, speeding up some processes and slowing down others to make them work together [11].

The results are encouraging, says Stephen Sofen, the project's director. The number of discrete operations involved in producing the drug was cut from 22 to 13; the processing time (even excluding all the moving around of materials) shrunk from 300 hours to 40. Instead of testing each batch of material, every pill made is monitored to ensure it meets the required specification [11].

Continuous manufacturing could transform the pharmaceuticals industry. “Instead of a giant, purpose-built plant to supply the global market, you could imagine smaller, regionalised plants,” says Mr Sofen. Such factories could respond more rapidly to local demand, especially if a pandemic were to break out. The pilot line in Cambridge will fit into a shipping container, so it could be deployed anywhere. It can make 10m tablets a year, working around the clock. It might also be used to make customised doses of drugs for particular patients. Continuous manufacturing could make more treatments commercially viable [11].

Genetically engineered viruses are being developed to make items such as batteries. The internet allows ever more designers to collaborate on new products, so barriers to entry are falling. Ford needed heaps of capital to build his colossal River Rouge factory; his modern equivalent can start with little besides a laptop and a hunger to invent [5]. Like computing before it, 3D printing is spreading fast as the technology improves and costs fall. A basic 3D printer in 2011 cost less than a laser printer in 1985 [7][9].

**Manufacturing still matters**

For more than 100 years, the US was the world’s leading manufacturer, but now shares top spot with China at about 20% of world output (see chart on manufacturing). In the decade to 2010, the number of US manufacturing jobs fell by about a third. The rise of outsourcing and offshoring and the growth of sophisticated supply chains has enabled companies the world over to use China, India and other lower-wage countries as workshops. Prompted by the global financial crisis, Western policymakers reckoned it was time their countries returned to making stuff to create jobs and prevent the export of more manufacturing skills. That supposes two things: that manufacturing is important to a nation and its economy, and that these new forms of manufacturing will create new jobs [11].

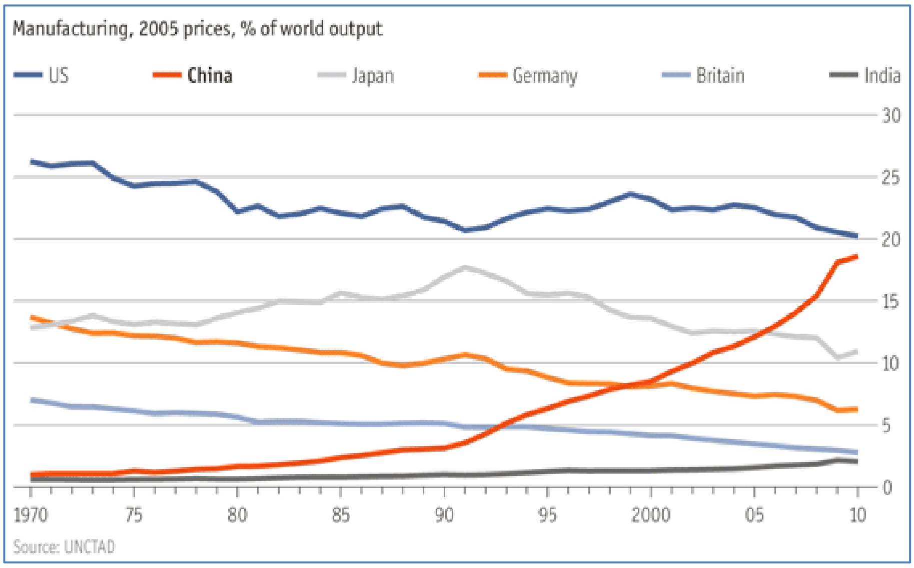
Plenty of research shows that manufacturing is good for economies, but in recent years some economists have argued that there is nothing special about making things and that service industries can be just as productive and innovative. It is people and companies, not countries, that design, manufacture and sell products, and there are good and bad jobs in both manufacturing and services. On average, though, manufacturing workers do earn more, according to a report by Susan Helper of Case Western Reserve University, Cleveland, for the Brookings Institution, a think-tank in Washington, DC [11].

Manufacturing firms are also more likely than other firms to introduce new and innovative products. Manufacturing makes up only about 11% of the US's GDP, but it is responsible for 68% of domestic spending on research and development. According to Ms Helper, it provides better-paid jobs, on average, than service industries, is a big source of innovation, helps to reduce trade deficits and creates opportunities in the growing “clean” economy, such as recycling and green energy. These are all good reasons for a country to engage in it [11].

Despite China's rapid rise, the US remains a formidable production power. Its manufacturing output in dollar terms is now about the same as China's, but it achieves this with only 10% of the workforce deployed by China, says Susan Hockfield, president of the Massachusetts Institute of Technology [11].

The “Hammering Man” catches a nostalgia for the kind of manufacturing employment, which in the developed world barely exists any more [11]. A factory floor today can seem deserted, whereas a nearby office block can be full of designers, engineers, IT specialists, accountants, logistics experts, marketing staff, customer-relations managers and other professionals, as well as cooks and cleaners, all of whom in various ways contribute to the factory [3,9]. Out-side the gates many more people are involved in different occupations that help to supply it. The definition of a manufacturing job is becoming increasingly blurred [11].

A lot of the jobs that do remain on the factory floor will require a high level of skill, says Mr Smith, Rolls-Royce's manufacturing boss. “If manufacturing matters, then we



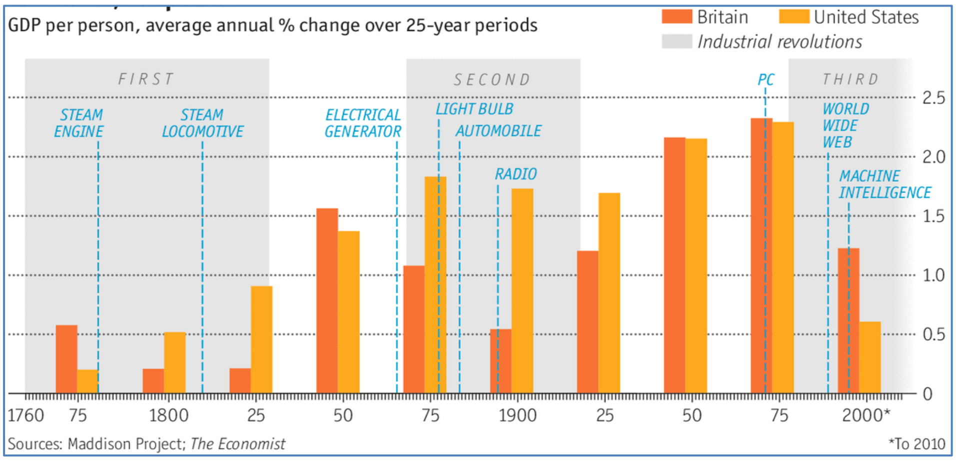
need to make sure the necessary building blocks are there in the education system.” His concern extends to the firm's suppliers, because firms in many countries have cut down on training in the economic downturn. To get the people it wants, Rolls-Royce opened a new Apprentice Academy to double the number of people it trains each year, to 400 [11].

Many people working in factories are providing services that are crucial to manufacturing. “In the future more products will be sold on the basis of service,” says Kumar Bhattacharyya, chairman of the Warwick Manufacturing Group at Warwick University. “If you sell a car with a ten-year warranty you need to make sure it will last for ten years and that you have the services in place to look after it” [11].

The revolution will affect not only how things are made, but where. The geography of supply chains will change. An engineer working in the middle of a desert who finds he lacks a certain tool no longer has to have it delivered from the nearest city. He can simply download the design and print it. The days when projects ground to a halt for want of a piece of kit, or when customers complained that they could no longer find spare parts for things they had bought, will one day seem quaint [5].

Factories used to move to low-wage countries to curb labour costs, but labour costs are growing less and less important: a $499 first-generation iPad included only about $33 of manufacturing labour, of which the final assembly in China accounted for just $8. Offshore production is increasingly moving back to rich countries not because Chinese wages are rising, but because companies want to be closer to their customers so that they can respond more quickly to changes in demand. Some products are so sophisticated that it helps to have the designers and engineers in the same place. The Boston Consulting Group reckons that in areas such as transport, computers, fabricated metals and machinery, 10-30% of the goods that the US now imports from China could be made at home by 2020, boosting US output by $20-55 billion a year [5].

The effect of technological change on trade is changing the tried-and-true method of economic development in poorer economies. More manufacturing work can be automated, and skilled design work accounts for a larger share of the value of trade, leading to what economists call “premature de-industrialisation” in developing countries. No longer can governments count on a growing industrial sector to absorb unskilled labour from rural areas. In both the rich and the emerging world, technology is creating opportunities for those previously held back by financial or geographical constraints, yet new work for those with modest skill levels is scarce compared with the jobs created in earlier technological revolutions (see chart, GDP per person) [6].



Sources: Maddison Project; *The Economist* *To 2010

**The jobless technology, productivity, wages and jobs**

A technological change so profound resets the economics of manufacturing. Digital technology is unsettling various industries and jobs, just as cotton mills crushed handlooms or as the Model T car displaced the horse and cart. By reducing the need for factory workers (or eliminating the factory), 3D printing will undermine the advantage of low-cost, low-wage countries and thus repatriate manufacturing capacity to the rich world. It might; but Asian manufacturers are just as well placed as anyone else to adopt the technology. Even if 3D printing does bring manufacturing back to developed countries, it might not create very many jobs because it is less labour-intensive than standard manufacturing [7].

The strides made in US manufacturing productivity does raise questions about how many manufacturing jobs, particularly of the white-collar variety, will be created. Some manufacturing breakthroughs will bring down the number of people needed even further. “It is true that if you look at the array of manufacturing technologies that are coming, many of them are jobs-free, or jobs-light,” says Ms Hockfield. “But that is no reason not to want to do that type of manufacturing in the US, because feeding into jobs-light processes is a huge supply chain in which there are lots of jobs and large economic benefits” [11].

The technology will have implications not just for the distribution of capital and jobs, but also for intellectual-property (IP) rules. Objects described in a digital file are much easier to copy and distribute, and to pirate. Digital technology rocked the media, music and film industries. When the blueprints for a new toy, or a designer shoe, escape onto the internet, the chances that the owner of the IP will lose out are greater [5][7].

Some economists are offering radical thoughts on the job-destroying power of this new technological wave. Carl Benedikt Frey and Michael Osborne, of Oxford University, analysed over 700 different occupations to see how easily they could be computerised, and concluded that 47% of US employment is at high risk of being automated over the next 10-20 years. Messrs Brynjolfsson and McAfee (2011) in “Race against the Machine” ask whether human workers are able to upgrade their skills fast enough to justify their continued employment [6][8].

The digital revolution is opening up a great divide between owners of capital and wealth and the rest of society, and between the skilled few and the less skilled majority. In the past new technologies have usually raised wages by boosting productivity, with the gains split between skilled and less-skilled workers, and between owners of capital, workers and consumers. Now technology is empowering talented individuals as never before and opening up yawning gaps between the earnings of the skilled and the unskilled, capital-owners and labour. At the same time it is creating a large pool of underemployed labour that is depressing investment [6].

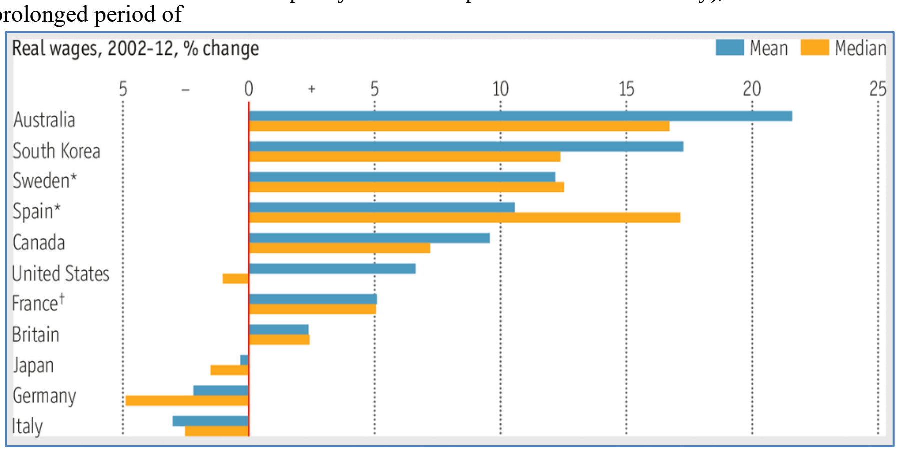
Fear of the job-destroying effects of technology is as old as industrialisation. It is often branded as the lump-of-labour fallacy: the belief that there is only so much work to go round (the lump), so that if machines (or foreigners) do more of it, less is left for others. This is deemed a fallacy because as technology displaces workers from a particular occupation it enriches others, who spend their gains on goods and services that create new employment for the workers whose jobs were lost through automation. A critical cog in the re-employment machine, though, is pay. To clear a glutted market, prices must fall, and that applies to labour as much as to wheat or cars [12].

The notion of a fading economic sector arises from a big drop in manufacturing employment over the past two decades. Some regions in the US were hit especially hard. From 1980 to 2005 the number of factory jobs fell by some 45%. Many, including President Trump, reckon that global trade, especially with China, is largely to blame. However, studies show that the majority of past factory job losses were the result of investments in automation, which continue to pay off. US manufacturing has more than doubled output in real terms since the 1980s, to over $2trn in 2017. Productivity is soaring. Output per labour-hour rose by 47% between 2002 and 2015, outpacing gains in the UK, France and Germany [13].


Productivity growth has always meant cutting down on labour. In 1900 some 40% of US labour worked in agriculture, and just over 40% of the typical household budget was spent on food. A century later, automation reduced agricultural employment in most rich countries to below 5%, and food costs dropped steeply. Labour was reallocated to new sectors, thanks in large part to investment in education [12].

Since the late 1970s, after the blistering growth in Europe and the US following the Second World War, workers have had tougher times (see chart, real wages). In the early 1990s Japan's economy entering a prolonged period of economic stagnation. The digital economy, far from pushing up wages across the board in response to higher productivity, is keeping wages flat for the mass of workers while rewarding the most talented ones [12].

Between 1991 and 2012 the average annual increase in real wages in the UK was 1.5% and in the US 1%, according to the Organisation for Economic Co-operation and Development, a club of mostly rich countries. That was less than the rate of economic growth over the period and far less than in earlier decades. Other countries fared even worse. Real wage growth in Germany from 1992 to 2012 was just 0.6%; Italy and Japan saw hardly any increase at all (see chart, real wages) [12].




It seems difficult to square this unhappy experience with the extraordinary technological progress during that period, but the same thing has happened before. Most economic historians reckon there was very little improvement in living standards in the UK in the century after the first Industrial Revolution. In the early 20th century, with the invention of electric lighting coming into its own, productivity growth and GDP per capita was every bit as slow as it has been in recent decades [12].

In July 1987 Robert Solow, a Nobel prize economist, wrote a book review for the *New York Times*. The book in question, "The Myth of the Post-Industrial Economy", by Stephen Cohen and John Zysman, lamented the shift of the US workforce into the service sector and explored the reasons why US manufacturing seemed to be losing out to competition from abroad. One problem, the authors reckoned, was that the US was failing to take full advantage of the magnificent new technologies of the computing age (e.g., increasingly sophisticated automation and much-improved robots. Mr Solow commented that the authors, "like everyone else, are somewhat embarrassed by the fact that what everyone feels to have been a technological revolution...has been accompanied everywhere...by a slowdown in productivity growth" [12].

The failure of this new technology to boost productivity (except briefly between 1996 and 2004) is called the Solow paradox. Economists disagree on its causes. Robert Gordon of Northwestern University suggests that recent innovation is simply less impressive than it seems, and not powerful enough to offset the effects of demographic change, inequality and sovereign indebtedness. Progress in ICT, he argues, is less transformative than the three major technologies of the second Industrial Revolution – electrification, cars and wireless communications (see previous chart, GDP per person) [12].

Yet the timing does not seem to support Mr Gordon's argument. The big leap in US economic growth took place between 1939 and 2000, when average output per person grew at 2.7% a year. Both before and after that period the rate was a lot lower: 1.5% from 1891 to 1939 and 0.9% from 2000 to 2013. The dramatic dip in productivity growth after 2000 seems to have coincided with an apparent acceleration in technological advances as the web and smartphones spread everywhere and machine intelligence and robotics made rapid progress [12].

A second explanation for the Solow paradox, put forward by Erik Brynjolfsson and Andrew McAfee (as well as plenty of techno-optimists in Silicon Valley), is that technological advances increase productivity only after a long lag. The past 40 years has been a period of gestation for ICT during which processing power exploded and costs tumbled. The transformational phase is only just beginning [6][12].

That sounds plausible, but the productivity statistics do not bear it out yet. John Fernald, an economist at the Federal Reserve Bank of San Francisco and an authority on US productivity figures, studied productivity growth over the past decade. He found that its slowness had nothing to do with the housing boom and bust, the financial crisis or the recession. Instead, it was concentrated in ICT industries and those that use ICT intensively [12].

A more promising place to look for improvements in productivity is in service sectors. In higher education, for example, the development of online courses could yield a productivity bonanza, allowing one professor to do the work previously done by many lecturers. Once an online course is developed, it can be offered to unlimited numbers of extra students at little extra cost. New techniques and technologies in medical care appear to be slowing the rise in health-care costs in the US. Machine intelligence could aid diagnosis, allowing a given doctor or nurse to diagnose more patients more effectively at lower cost. Mobile technology to monitor chronically ill patients at home could also produce huge savings [12].

Such advances should boost both productivity and pay for those who continue to work in the industries concerned, using the new technologies. Those services should become cheaper for consumers. Health care and education are expensive, in large part, because expansion involves putting up new buildings and filling them with costly employees. Rising productivity in those sectors would probably cut employment [9].

The lines between manufacturing and services are blurring. Rolls-Royce no longer sells jet engines; it sells the hours that each engine is actually thrusting an aeroplane through the sky. Governments have always been lousy at pricking winners, and they are likely to become more so, as legions of entrepreneurs and tinkerers swap designs online, turn them into products at home and market them globally from a garage. As the revolution rates, governments should stick to the basics: better schools for a skilled workforce, clear rules and a level playing field for enterprises of all kinds. Leave the rest to the revolutionaries [5].

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