IPS
Class
INDUSTRIAL REVOLUTIONS
To what extent is this one the fourth?

Sandrine Labory

The first thing to find out in order to understand the fourth industrial revolution, is what were the previous industrial revolutions about?

An important aspect to analyse in order to characterise industrial revolutions is technological change: each industrial revolution is associated with specific innovations and new technologies.

However, other factors determine industrial revolutions: in particular, political, cultural and social changes.

OUTLINE

1. First industrial revolution
2. Second industrial revolution
3. Third industrial revolution
4. Factors characterising industrial revolutions
   - Technological innovations and systems
   - Political, cultural and social changes

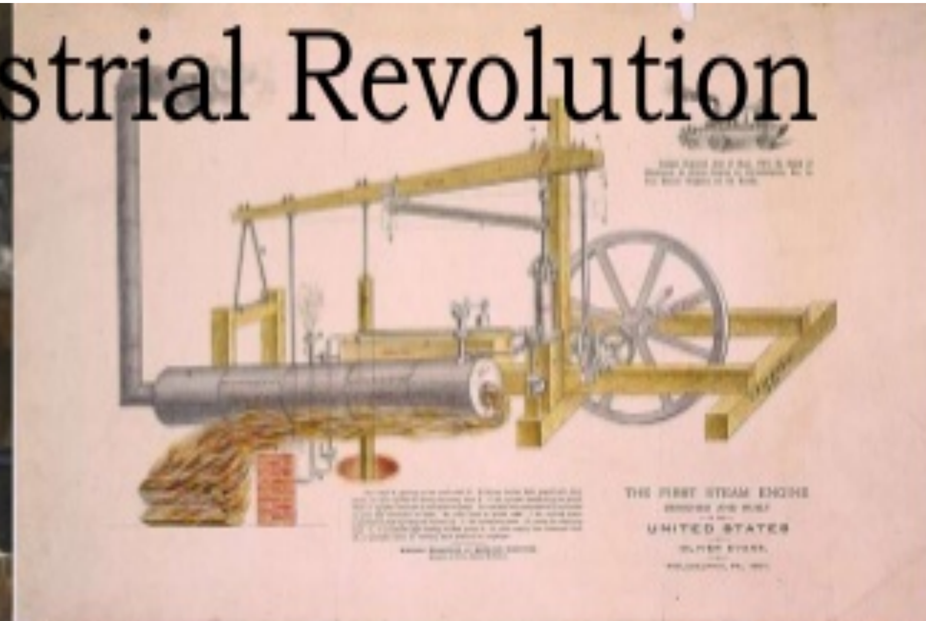
1. First industrial revolution

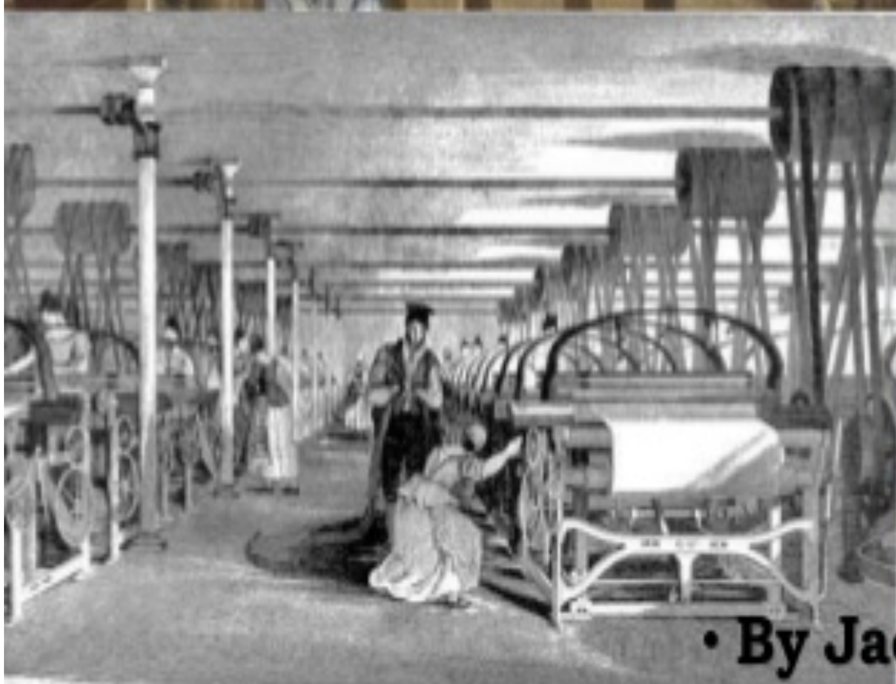
The first industrial revolution lasted about 70 years and is generally dated between 1760 and 1830.

Some of the industries, which became characteristic of the first industrial revolution were already growing in the XVI and XVII centuries (textile for instance).

During the first industrial revolution the rate of growth accelerated, a wave of inventions and innovations occurred, and production organisation really shifted from craftsmanship to factory work.

The First Industrial Revolution





- **By Jack Garrity**

The **cotton and iron industry** were the leading industries of the change.

Cotton

The share of cotton in total value added of industry grew from 2.6 in 1770 to 17 per cent in 1801.

Many inventions, from the jenny to the water-frame and the mule.

The number of patents was about 80 per year in the 1740s, increased to nearly 300 in the 1770s and over 600 in 1790s.

Productivity rose dramatically: working hours for spinning 100 pounds of cotton reduced by 85% from 1780 to 1795 and by 93% from 1780 to 1830.

Iron

The smelting of iron ore with coke instead of charcoal and Cort's process for the conversion of pig iron into malleable (wrought) iron by 'puddling' were the two decisive innovations for the metalworking industries in the 18^{th} century

Innovations made possible a huge increase in supply of relatively cheap iron between 1780 and 1840.

Some complementary innovations were made. For example Smeaton invented a water-powered mill done in iron and not wood so that it was much more energy-efficiency.

The falling price of iron enabled its use in many techniques and processes: bridges, ships and buildings could be made with iron in their structure, making them lighter and more resistant.

Transport infrastructure

The first wave of industrialisation depended on water power, canals and much better roads.

The British government made huge investments in these infrastructures (helped by the creation of the Bank of England in 1694, which provided regular trade in government bonds during the first industrial revolution).

The first industrial revolution implied important and wide changes, not only in the economy, but also in the society and culture.

Even the agricultural sector became organised along capitalist lines.

It is widely recognised that the **early abolition of serfdom** in Britain contributed to the industrial revolution because it freed workers from rural areas that could go and work in the factories located in cities. The **political system** in Britain also favoured the first industrial revolution, since it gave power even to the bourgeoisie and not only to nobles, in the **Parliamentary monarchy**.

Adam Smith’s book The Wealth of Nations exemplified the political and cultural foundations of the British industrial revolution.

He showed the benefits of having entrepreneurs looking for profits and hiring workers in factories

He criticised the maintenance of local monopolies and restrictions on trade.

He also underlined the benefits of access to decent living conditions for all people, including workers, allowing civil development to the benefits of the whole country (social sustainability)

The first industrial revolution was the work of very small firms: hardly any firms employed more than a hundred people, and even by the 1840s only a very few firms, mainly in the cotton and iron industries, employed over a thousand.

During the next decades this number steadily increased, including some large railway companies and engineering firms.

In European countries too, the more successful firms were growing in size and market power.

The first industrial revolution **did not have a strong scientific base**:

Innovations in technologies were made by trial and errors without links between science and technology

Firms created were essentially SMALL:

hardly any firms employed more than a hundred people

Firm size grow steadily in the 19^{th} century, up to large firms establishing in the second IR

The Second Industrial Revolution

Inventions and Innovations that changed the world!

2. Second industrial revolution

The second industrial revolution lasted about 60 years and is generally taken to have lasted between 1860-70 and 1914-20.

There were many innovations in energy materials, chemicals and medicine.

The second industrial revolution is characterised by **considerable feedback from technology to science**: scientific thinking focused on potential technological applications, and technological applications also focused on developing instruments allowing the test of scientific theories.

The second industrial revolution has thus two important characteristics.

1. It is about the **interaction between science and technology**, in the sense that technological developments were backed and supported by important improvements in science.

Mowery and Rosenberg (1989) have characterised the period 1859-1873 as the most fruitful and dense in innovations in history.

Second, it is characterised by an important change in the **organisation of production**, allowing large economies of scale and price reductions, implying rising extent of markets as more and more consumers could afford the good: **MASS PRODUCTION**

The new technology of production combines different technologies: machines, electricity and power generation, chemical innovations, and so on.

The automobile is a product developed from the **convergence** of different sciences and technologies: chemicals (oil refinery and fuel production; rubber and tire production), engineering and electricity, steel and metal working, etc.

Scientific production (Taylor) and mass production will be experienced in this sector at the beginning of the 20^{th} century with Henri Ford producing the model Ford-T with this production line.

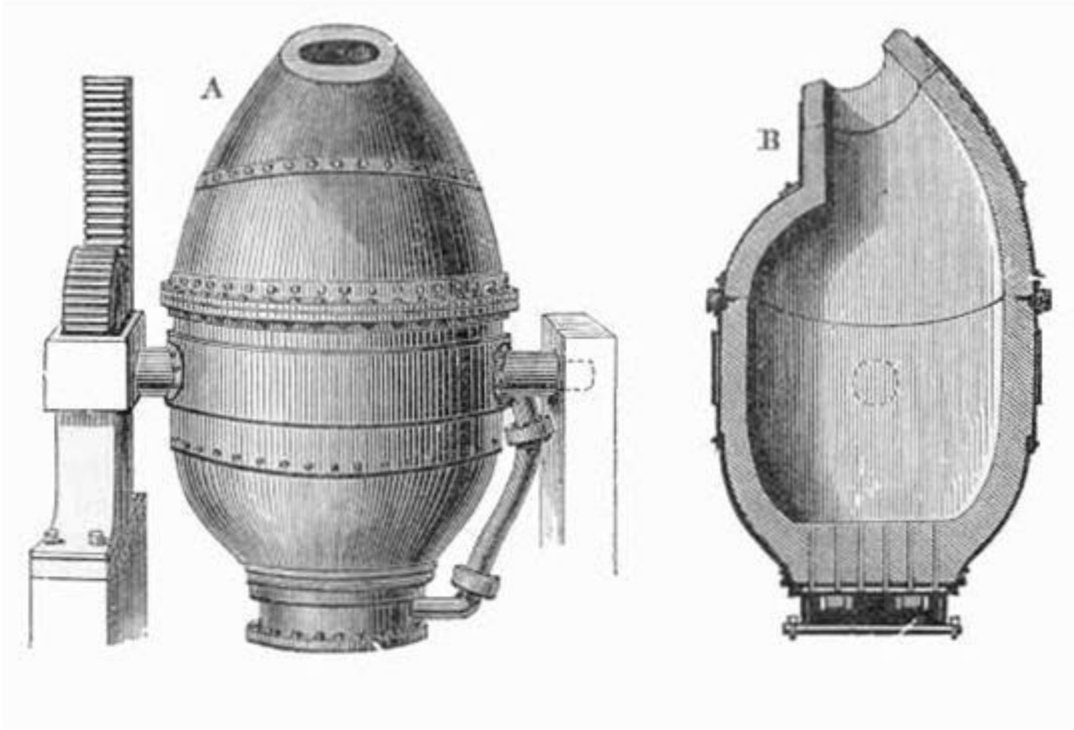
Important industries of the second industrial revolution

STEEL

Henry Bessemer invented the first low-cost process of making steel in 1856. The steel industry considerably developed afterwards, since steel had many advantages over iron (resistance and strength, light weight, no oxidation) in the composition o many products, including railways, ships and machine tools.

Bessemer process

- Henry Bessemer
  - patented in 1855
- First inexpensive industrial process for mass-production of steel from molten pig iron
- Key principle – removal of impurities by oxidation
  - air blown through the molten iron



CHEMICALS

William Perkin (UK) made the first important discovery that spurred the development of the modern chemistry industry: he discovered the aniline purple, leading to the development of artificial dyes in the chemical industry.

⇒ Development with also production of fertilisers and artificial materials.

⇒ Charles Goodyear invented in 1839 the vulcanization process that made widespread industrial use of rubber possible.

⇒ John Wesley Hyatt invented in 1869 the first synthetic plastic, which he called celluloid

From 1815 to 1845, a new constellation of industries, services and technologies rapidly grew, but the society and polity also experienced important turmoil.

Napoleonic wars: negative impact also on the British economy, since France and other European countries involved in the wars reduced their imports from Britain.

After these wars other countries in Europe started their industrial revolution (France, Germany, Italy)

New technologies developed, including infrastructure (railways), new source of power (steam engines) and new machine tools so that other European countries combined together the features of the first and of the second industrial revolution.

Railways developed considerably in the second half of the 18th century, in Britain but also in Germany and in France.


1168
1168


TITANIC

Railways brought more than just cheaper and more rapid transport.

The smooth and efficient management of railways indeed required **new management features**, such as punctuality, forward planning of services, regular maintenance, speed of delivery for goods and travellers…

All these organisational practices were facilitated by another technical and organisational innovation – the electric telegraph, invented by Wheatstone in 1837 and diffused very rapidly along the railway tracks in the 1840s.

The organisational innovations in the railway sector had impact in other sectors, where the new organisational practices were copied, for instance in the coal, iron and engineering industries.

The machine tool industry, namely the production of machines to make machines, particularly developed during the second industrial revolution. According to Musson (1980) it was in fact the British machine tool industry that pioneered mass production.

Britain was the leader of the first industrial revolution;

The USA became the leader in the second IR (large market, democracy, huge investments and gold fever, new education system forming bureaucrats and managers)

ELECTRICITY

The electricity industry was much more closely related to science than the industries of the previous waves.

Benjamin Franklin undertook various experiments with electricity in thunderstorms in the 1740s, as did other scientists.

In 1800 Volta invented the primary battery.

ELECTRICITY

All through the 19^{th} century research continued on electricity.

In the 1850s and 1860s the magnetos and dynamos reach a development point where they could be used on a commercial scale for illumination.

Then the electric industry develops with many applications.

Chandler (1977) highlights the speed of electricty adoption in the USA: by 1890 15% of urban transit lines were using electric-powered street cars, and by 1904 this had risen to 94%.

⇒important changes in the society and the economy:

Offices and firms could be organised differently, because lighting would allow to work any time of the day or night.

The telephone facilitated the administration of large organisations, but also small firms benefitted.

The growth of the new electricity infrastructure required a new regulatory framework, new legislation, new standards, and massive private and public investment.

3.Third industrial revolution

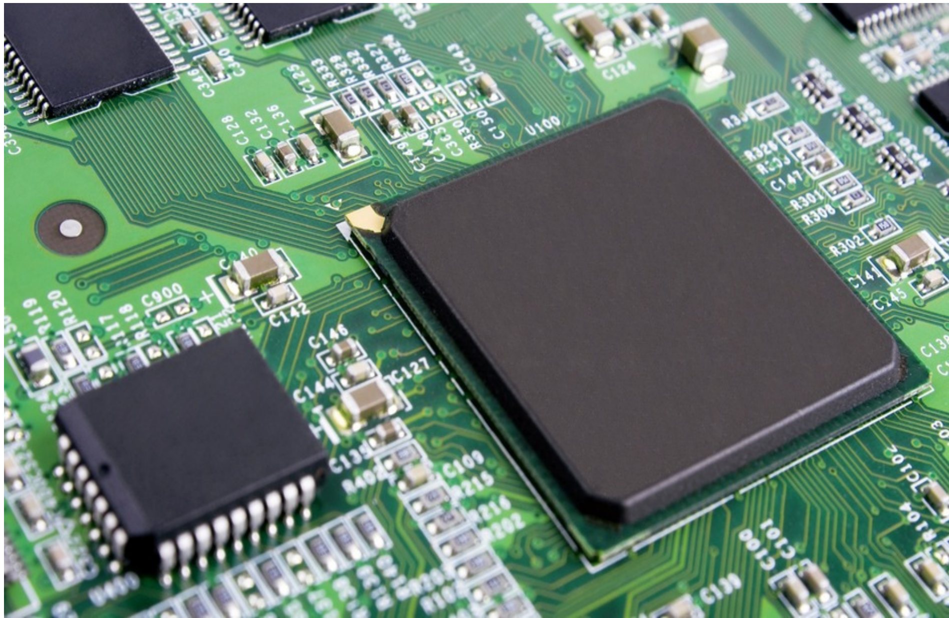
ICTs are the key technologies of the third industrial revolution

The development started in the 1950s, in terms of science and invention, but the macroeconomic effects of the ICTs were felt much more in the last quarter of the 20^{th} century.

ICTs consist in different technologies, namely electronics, computer and telecommunications, that have been developed and constantly improved all through the 20^{th} century and that have converged in the last quarter of the century.

One of the important innovation leading to the development of computers has been the computer chip. In fact, integrated circuits have been improved rapidly and constantly: Moore’s law has largely held.

Moore enunciated his law in 1965, predicting that the capacity of a computer chip would double every year, then in 1975 he predicted that the capacity would double every two years.




IBM
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ICTs in fact originate in the development of electronics all through the 20^{th} century, generating numerous innovations in radio, radar and television.

Like the electric industry, the growth of the electronics industry was made possible mainly by European research and innovations. Thus for instance Hertz and Maxwell theorised and demonstrated the existence of electromagnetic waves.

The electronic and ICT sector are characterised by a strong interaction between scientists and engineers as a basis of the innovation process, so that countries with strong scientific institutions, as well as entrepreneurial engineers, have taken the lead.

The first thermionic valve was invented and patented in 1904 by Sir John Ambrose Fleming, a professor at London University

⇒ Up to WWI the radio industry was dominated by British and German firms.

⇒Guglielmo Marconi established his Wireless Telegraph Company in Britain in 1897 and first demonstrated the feasibility of ship-to-shore radio communications, as well as shore-to-shore and ship-to-ship. His firm in Britain was however closely followed by the German electrical giants, AEG and Siemens.

- After WWII all governments supported R&D for electronic components and circuits.
- It was in the Bell laboratories of AT&T that civil transistor technology led to the key developments in semi-conductors and to the establishment of the US semi-conductor industry, mainly by spinoff from the Bell Laboratories. The role of government continued to be important but more in the procurement of new devices.

The microprocessor was developed by Intel in 1971-2.

It had a big impact on the semi-conductor and computer industries because it meant that a ‘computer on a chip’ could be manufactured at low cost and large scale.

The US dominated the semi-conductor industry in the 1970s, 1980s and 1990s, although Japanese firms also became important players in the market. R&D efforts by US firms were supported by the US government Sematech project.

Telecommunications

This sector has developed through successive innovations for a long time (starting from invention of telephone by Alexander Graham Bell in 1875),.

1990s = most drastic innovations, making the sector no longer a natural monopoly and allowing it to converge with computers to contribute to the new industrial revolution based on ICTs.

Parallel to the development of telephone capacity an important field of technological improvement was in the carrying capacity of cables.

In the 1990s cables were improving a lot but at the same time new communication infrastructure was developing: wireless communication, which was developing thanks to satellites and digital systems.

The essential facility could thus be duplicated and the sector was no longer characterised by natural monopoly.

The internet was originally introduced in the 1960s as an advanced research project agency (ARPA) project, supported by the Pentagon in the US to ensure that some decentralised communication would remain in operation even in the event of a nuclear war.

Today the telecommunication sector and ICTs continue to be the leading industry in terms of growth, innovation and impact on other industries.

Mobile devices and broadband connectivity are increasingly imbedded in modern economies and societies.

Virtually any industry benefits from telecom innovations and probably the most important impact is now in the internet factory and the Internet of Things.

4. Factors characterising industrial revolutions

Industrial revolutions are generally determined by important technological progress, implying new products and production processes, leading to new industries.

These new industries grow fast ➔ rising economic growth + development of other industries

For instance, ICTs have pervasive impact on all sectors of the economy.

Industrial revolutions may also be characterised by their core inputs: iron for the first industrial revolution, steel and electricity for the second.

Industrial revolutions are characterised by the creation of new technological systems (Gille, 1978) or technological constellations (Freeman and Louça, 2001).

Many economists and historians of technology have stressed the importance of the systemic feature of technology (Gille, 1978; Hughes, 1982). The innovation and diffusion of new products and new processes are not isolated events but are always and necessarily related to the availability of materials, energy supply, components, skills, infrastructure, etc.

As Schumpeter observed, innovations often appear in clusters and are not evenly distributed in time and space.

This is reasonable since the invention of a new generic technology often finds applications in different products and sectors, so that a wave of innovations is observed from the specific innovation.

Nelson and Winter (1977) described this phenomena as generalized natural trajectories.

Impact of technological innovations may be differentiated across countries, depending on their industrial base, the availability of skills, and their capacity of adaptation.

The political system might have an influence too, favouring particular types of applications of the new technology for instance as in a case of a dictatorship strengthening the military apparatus.

In fact historians have stressed the importance of culture and the political system in industrial revolutions. British early end of serfdom; lumières before first industrial revolution

	First Industrial Revolution	**Second Industrial Revolution**	**Third Industrial Revolution**
Main technologies	Water-powered mechanization of industry	Steam power Electricity Combustion engine	ICTs Nuclear power generation
Leading industries	Cotton, Iron	Railways, machine tools, alkali industries	Computer and software Automobile, Aircraft
Core inputs and other key inputs	Iron, raw cotton, coal	Steel, copper, metal alloys	Oil, gas, synthetic materials, Chips

	First Industrial Revolution	**Second Industrial Revolution**	**Third Industrial Revolution**
Example of innovations	Arkwright's Cromford Mill (1771) Henry Cort's puddling process	Liverpool-Manchester railway (1831) Brunel's steamship Bessemer process Edison's electric power station (1882) Ford's assembly line (1913)	IBM 1401 and 360 series (1960s) Intel microprocessor (1972)

	Fourth Industrial Revolution
Main technologies	ICTs, genomics, biotechnologies, nanotechologies, Big data analytics, quantum computing, artificial intelligence
Example of innovations	First quantum computer, Orion by D-Wave Systems (2007)
Leading industries	ICTs, Platform businesses
Core inputs and other key	Data, sensors

One could go on characterising the different industrial revolutions:

Energy:

- First IR: water power
- Second IR: steam, electricity
- Third: oil and gas, nuclear
- Fourth: renewables

Industrial revolutions imply structural changes

Namely changes in the structure of the economy, starting from production organisation:

- First IR: from craft production to factory system
- Second IR: mass production system
- Third: flexible production system
- Fourth: mass customisation

Division of labour and production systems

Smith pin factory

In craft production, a single worker performs all the productive phases:

Pin production process of a single craftsman

RM	1	2	3	4	5	6	7	8	9	10	11	12	FP

Division of labour and production systems

The pin production process can be divided into twelve phases: wire-drawing, wire-straightening, cutting, pointing, pinhead making, pinhead finishing, pinhead and pin assembly, finishing, washing, realisation of boxes, box filling and box closing, leading to the final product.

The craftsman sequentially realises all the phases.

Production can be increased by adding a second craftsman

Fordist production system (mass production)

Each worker A, B, … performs a specific task of the production process.

Fordist production system

Phases	1	2	3	4	5	6	7	8	9	10	11	12	FP
Workers	A	B	C	D	E	F	G	H	I	J	K	L	

Fordist production system (mass production)

The production process is divided into very elementary tasks, each produced by a different worker along the assembly line.

The product is homogenous: e.g. black Ford-T

The production process is extremely rigid: new models can only be produced by building new assemble lines.

However, economies of scale a high: hence price can substantially reduce

Fordist production system (mass production)

Firms are vertically integrated: very large

SMEs are craft firms, or suppliers of large firms

Flexible production system

Introduced by Japanese producers in the 1980s.

The system combines economies of scale and economies of scope, by allowing a certain degree of differentiation of the product.

Flexible production system

Model 1	1	2	3	4	5	6	7	8	9	10	11	12	FP
Model 2													
Workers	A				B	C	D	E		F	G	H	

Flexible production system

Some phases of the production process are common to different models, so that there can be eocnomies of scale, but differentiation is introduced.

Production phases are often grouped into modules and workers can perform multiple tasks (e.g. workers A and E above).

➔ **Can be done also by SME systems**

Mass customisation

Today with the use of robots and cyber-physical systems differentiation can be substantially increased, so that products can even be personalised (it is enough to change the programming of the highly automated system).

Production is still divided in tasks that robots or humans perform, together or separately.

Economies of scale: initial fixed cost of the factory and machines; but the same factory can be used for a long time even as products change a lot

Transitions in Manufacturing Regimes

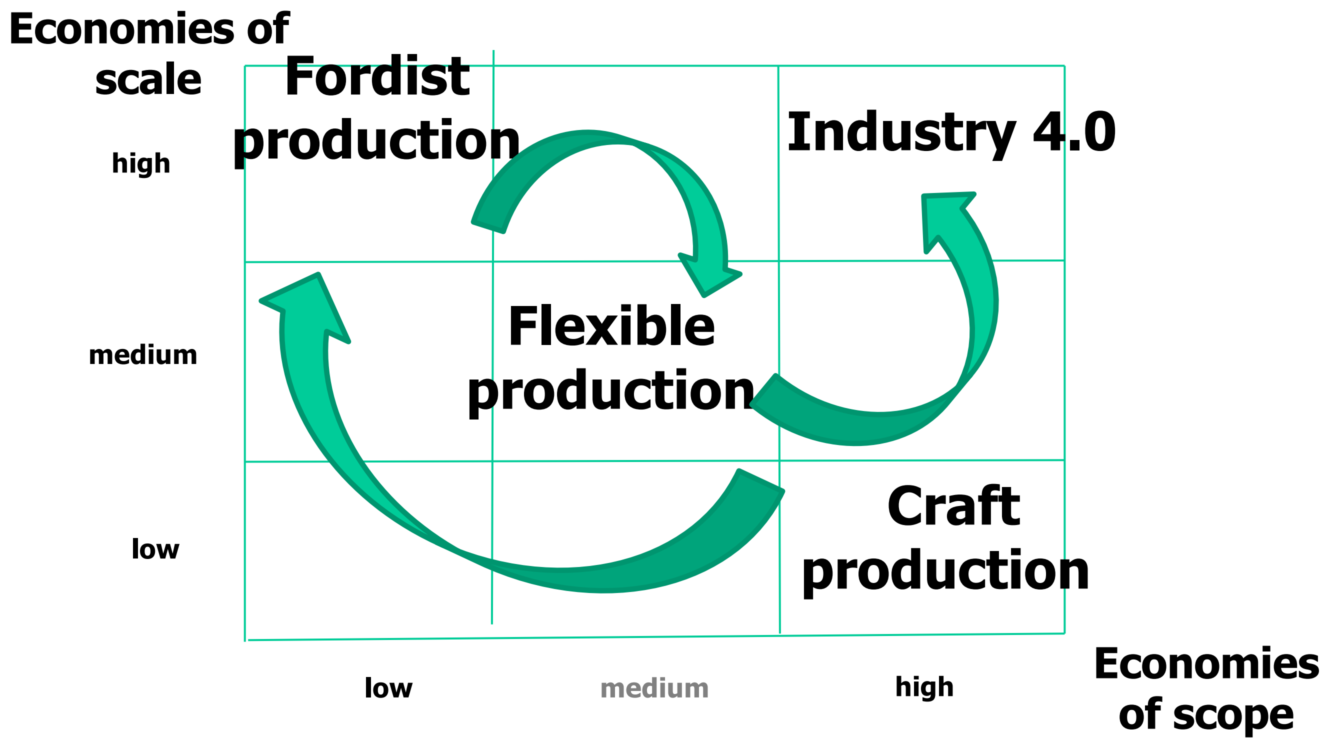
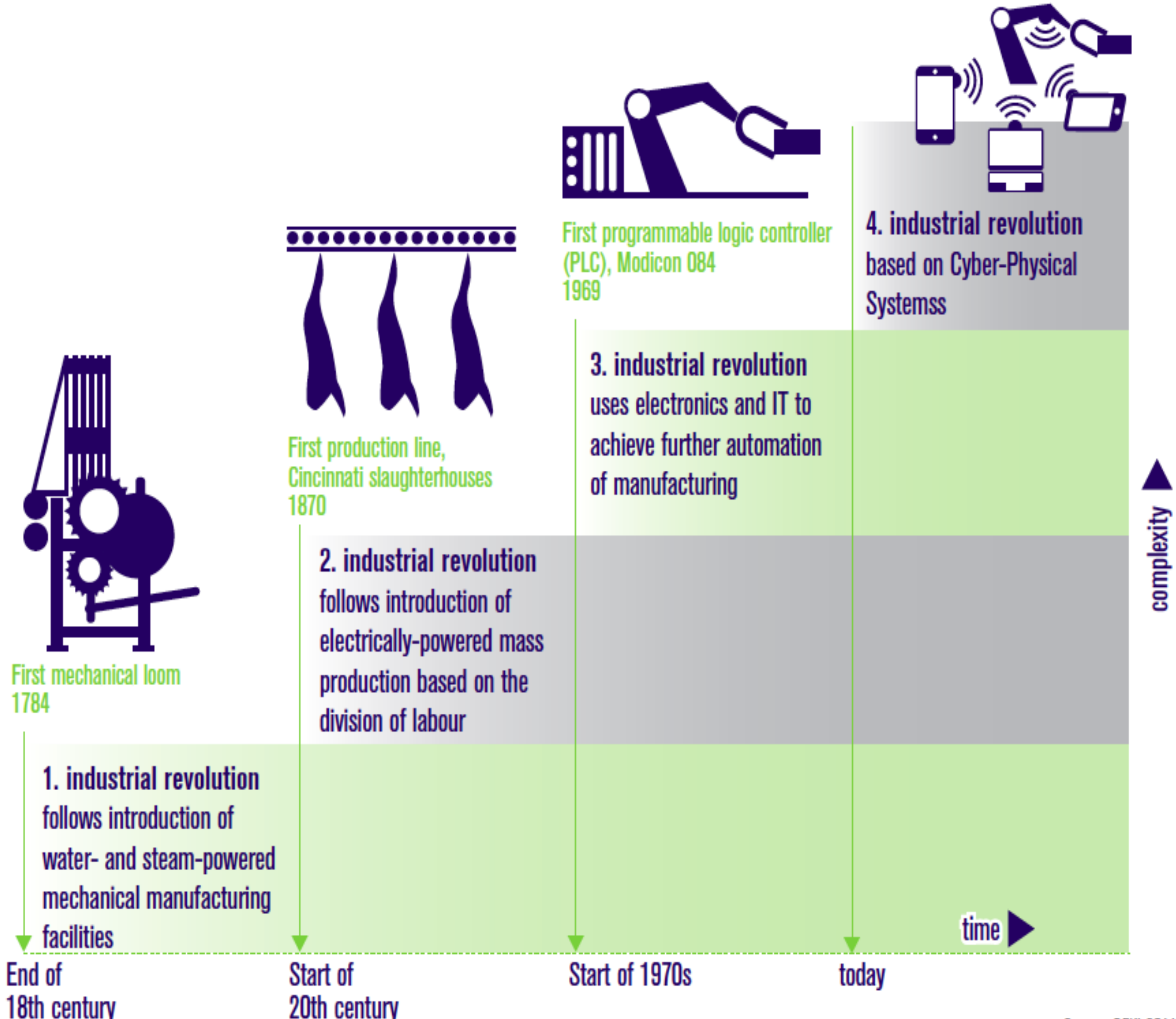


Figure 1:
The four stages of
the Industrial Revolution



Source: DFKI 2011

CONCLUSIONS I

Industrial revolutions represent complex changes in the economy and the society, corresponding to the birth of capitalism (first industrial revolution) and its development (second and third).

Capitalism ⇔ market economy (exchange between subjects with equal rights)

CONCLUSIONS II

Industrial revolutions are made possible by important technological innovations, leading to new technological systems, but there are also determined by political, cultural and social changes: end of feudalism for the first industrial revolution, new political regimes such as parliamentary monarchy (UK), Republic (France), Unification (Germany and Italy)

CONCLUSIONS III

The fourth industrial revolution, namely the spread of cyber-physical systems, hyper-connection, is in many ways the continuation of the 3rd industrial revolution: the main technology is ICTs, the main raw materials are data, …

However, it may really be a new revolution because it induces a very deep change:

The diffusion of <u>technosciences</u>, namely the real integration between science and technologies

Is the fourth industrial revolution an opportunity for SMEs?

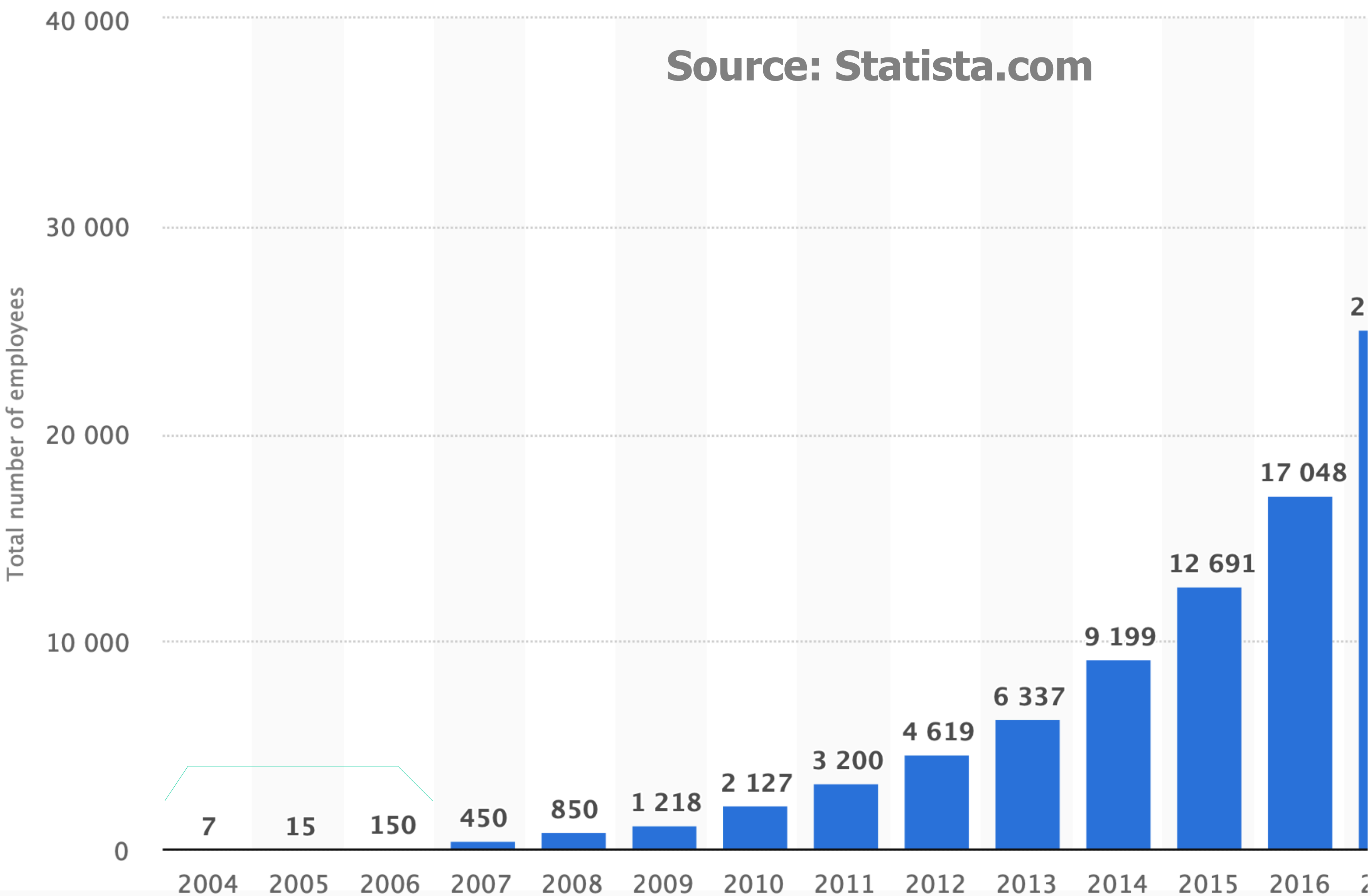
Industrial revolutions create **disruptions** to existing businesses

Which fail if they are unable to adapt

Leaving room for new firms, SMEs, that may grow

e.g. Facebook created by Marck Zuckerberg in 2004 with 4 colleagues…

Number of full-time Facebook employees from 2004 to 2018



Example: disruption implied by shift to electricity at the beginning of the 20th century

USA: 40% of the industrial trusts formed between 1888 and 1905 had failed by the early-30s

Manufacturing firms that were dominant in their markets in 1905 saw their average market share decline from 69% to 45%

Failing firms did not redesign their production process by effectively electrifying it

NEXT CLASS:

THE FOURTH INDUSTRIAL REVOLUTION

(or the third industrial revolution continued?)