A Production Revolution in the Making:

How industrial policies are building new industrial ecosystems in the OECD countries.

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Background – **Global transformations**

- Changes in global and regional production networks have restructured the **architecture of national and regional industrial ecosystems as well as the geography of production and international trade.**
- Emerging technologies and their integration into complex technological systems have led to fundamental shifts in **value creation and capture processes** in manufacturing production.
- The increasing **application of automation, robotics, and digital technologies** – coupled with new developments in nanotechnologies and biotechnologies – are triggering **technological change in products and processes, whilst increasing interdependences between organisations, industries, and regions.**

Background – **Policy responses**

- Against this background, and in particular in response to the so-called "Fourth Industrial Revolution" (FIR), **governments have been increasingly providing additional incentives and supports to emerging technologies (e.g. synthetic biology, IoT, robots, etc.) and strategic sectors (e.g. aerospace, automotive, pharmaceutical, etc.), above and beyond the existing industrial policies.**

- **<u>Industrial policies are back</u>, in many cases have never left in fact, but are certainly changing as a result of** (sometimes in view of steering) **the dramatic transformations we are witnessing in the global manufacturing and technology landscapes.**

Paper outline

1. A production revolution?
2. What is really "revolutionary" about the current "production revolution"?
3. How is "technology fusion" changing industrial policy among the OECD countries?
4. How industrial policies are building new "industrial ecosystems" in the OECD countries?
5. Discussion of industrial policy implications

A Production Revolution?

The term Industry 4.0 (or FIR) is mainly used with reference to the **increasing adoption of emerging digital technologies** (IoT, Big Data, cyber-physical systems) and associated technologies from machine learning and data science **underpinning increasingly autonomous and intelligent systems**.

Other emerging technologies (and related technology platforms) include **advanced materials**, **nanotechnologies** and **biotechnologies**, as well as **novel production technologies** such as additive mfg/3D printing.

The contrast is made with the **3 previous industrial revolutions**:

1. Advent of steam-powered mechanical production equipment (1780s >)
2. Electrically-powered mass production (1870s >)
3. Electronically-based automated production (1960 >)

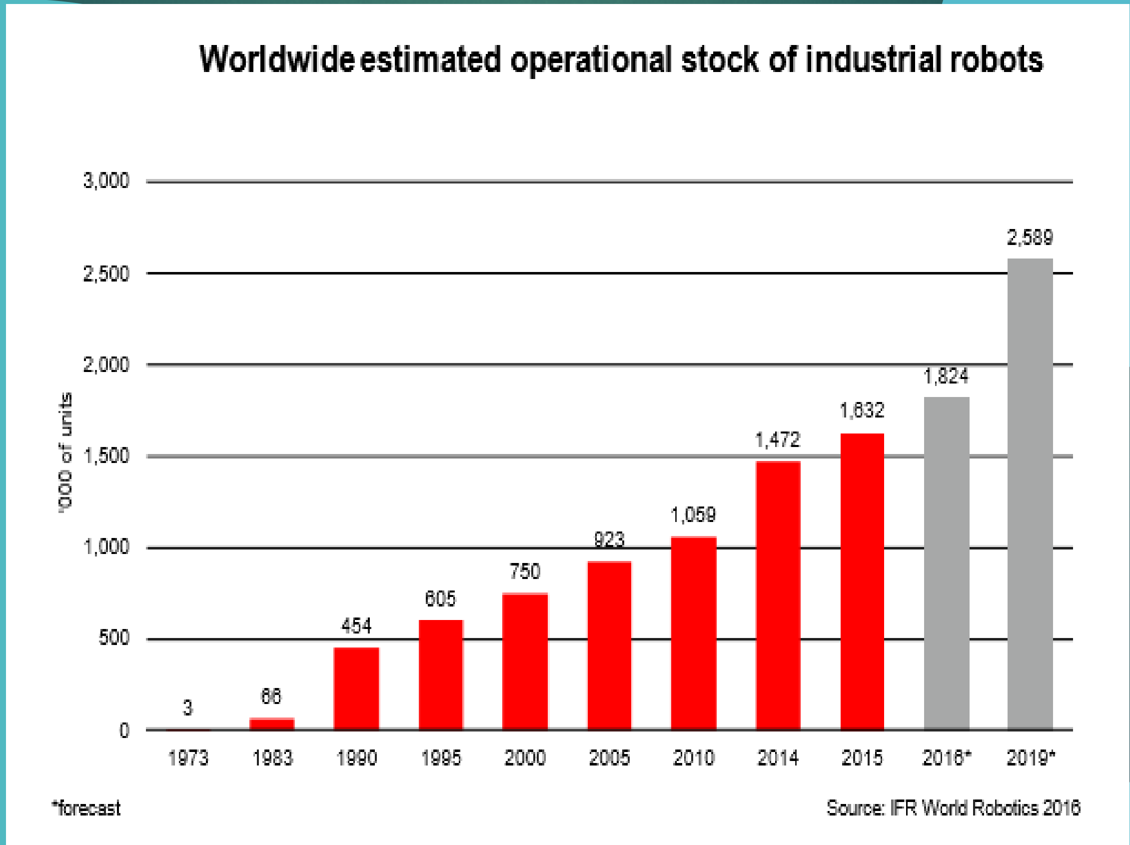
Are we really facing a new revolution/new technology paradigm or simply a development of the third revolutions?

Some of these technologies have been emerging for a long time…

A Production Revolution?

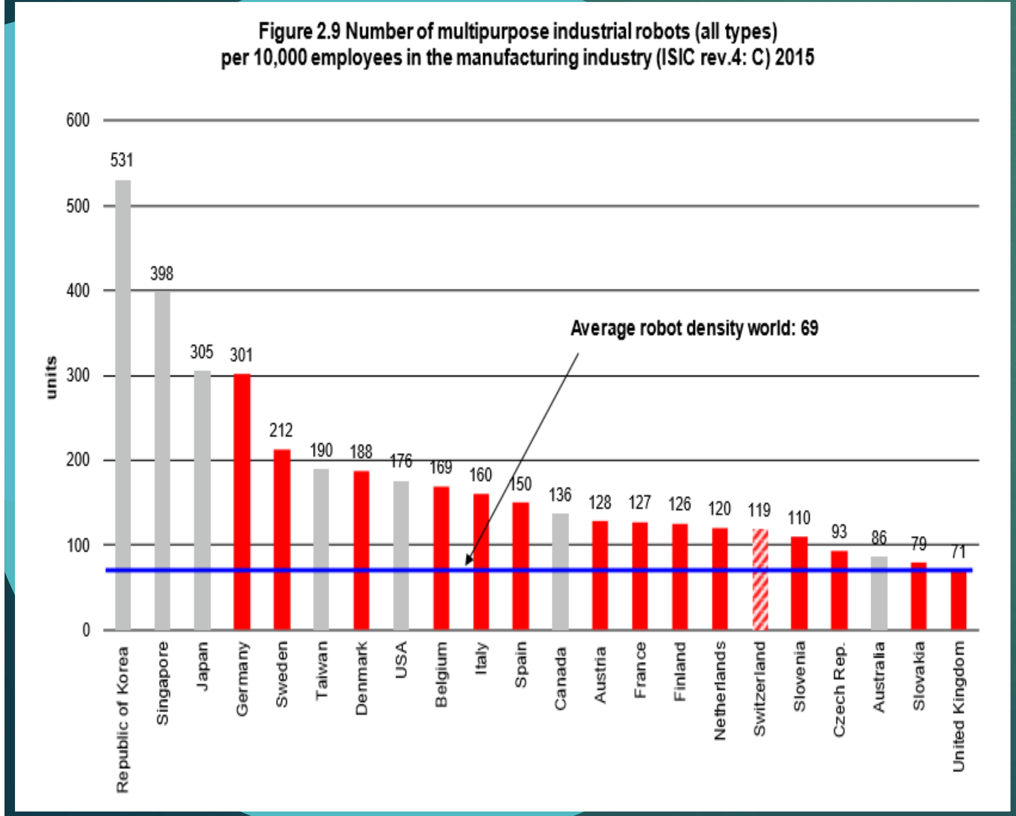
Let's take the **industrial robots** example

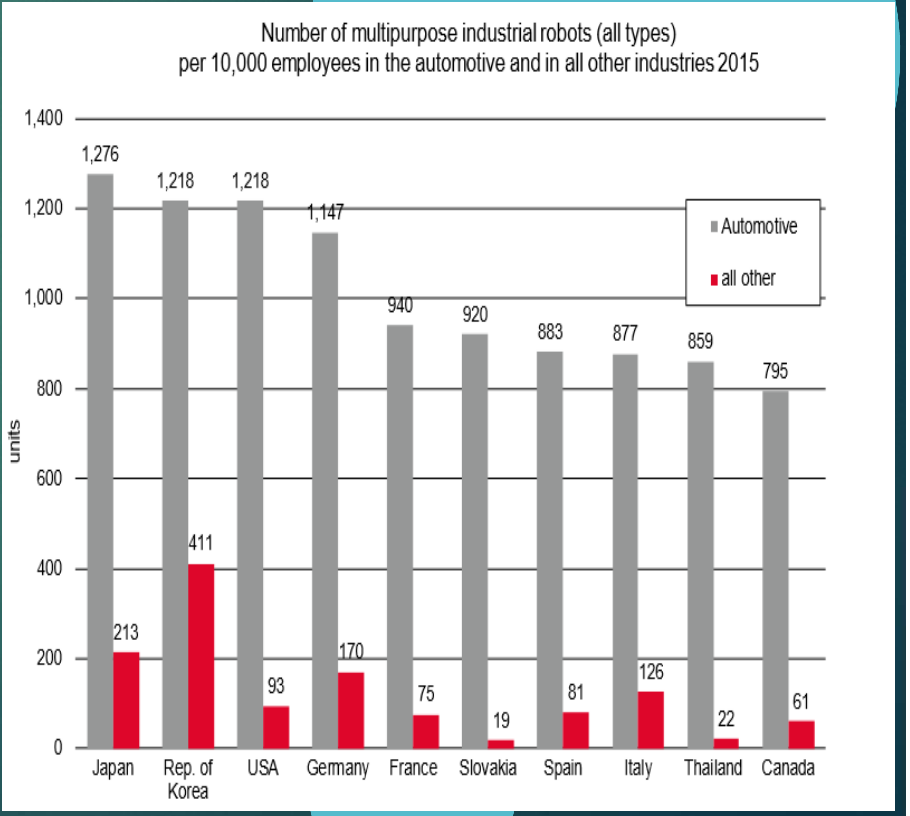
- the ISO (International Organization for Standardisation) and the IFR (International Federation of Robotics) define the industrial robot as: *"An automatically controlled, reprogrammable, multipurpose manipulator, programmable in three or more axes, which may be either fixed in place or mobile for use in industrial automation applications."*



A Production Revolution?

- Average density of multipurpose industrial robots is only 69/10.000Workers
- Industrial robots have been mainly deployed in automotive (and electronics..)





What is really "revolutionary" about the current "production revolution"?

What is really revolutionary is not particular technologies like robotics, BUT new complex forms of **"technology fusion"**

"Technology fusion": The fact that many of these emerging technologies:

- result from the ***convergence*** between different science and engineering domains/bases
- have been **"fused"** with each other **in *new technology systems (beyond mere combinations)***
- have increasingly found **completely new applications** within and across sectors, activities, processes and products

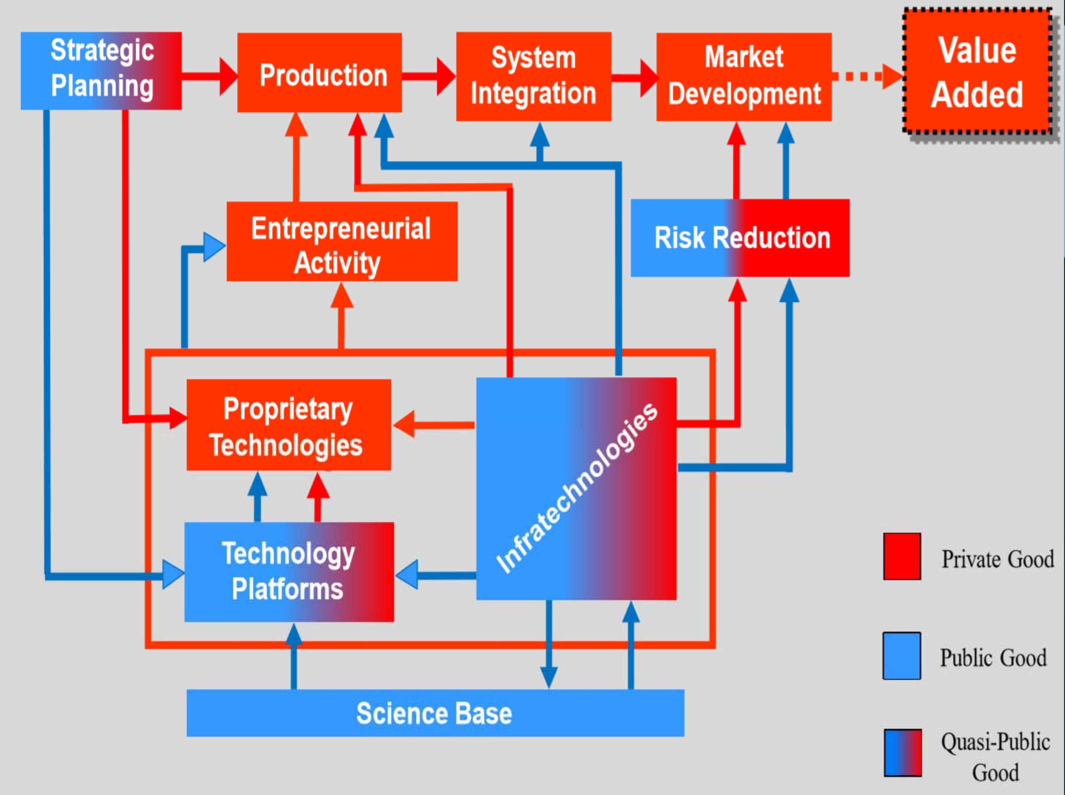
(Kodama, 1994; patents convergence analyses)

What is really "revolutionary" about the current "production revolution"?

Technology fusion into "revolutionary" technology systems

''Most **modern technologies are systems**, which means interdependencies exist among a set of industries that contribute advanced materials, various components, subsystems, manufacturing systems and eventually service systems based on sets of manufactured hardware and software''

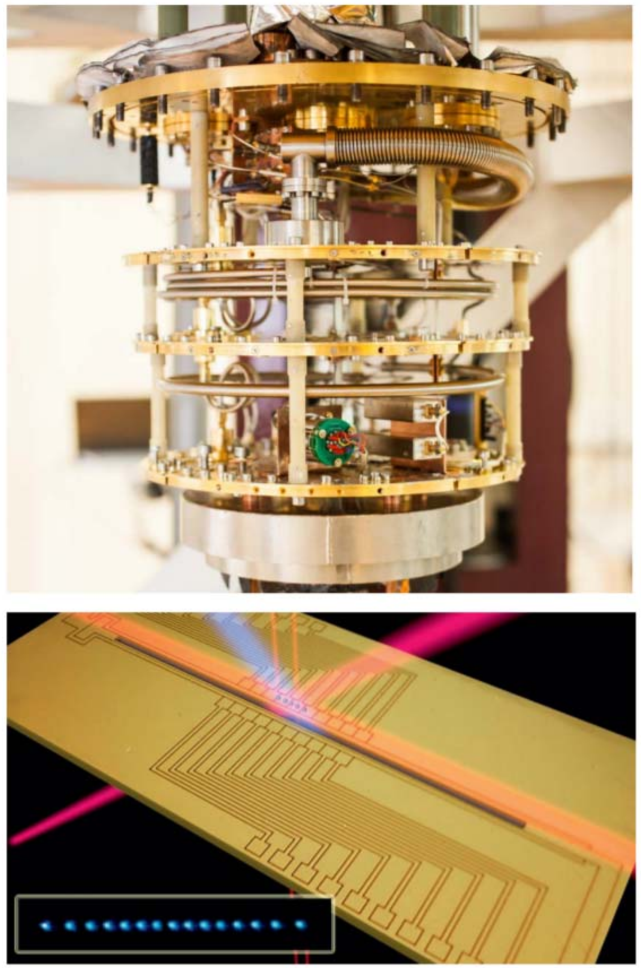
(Gregory Tassey, 2010, 6)



Gregory Tassey, *The Technology Imperative*, 2007; and, "The Disaggregated Technology Production Function: A New Model of Corporate and University Research," *Research Policy*, 2005.

Example of **technology fusion: quantum technologies**

- Technologies based on the laws of **quantum mechanics**
- **Technology fusion with advanced materials and digital technologies has** far-reaching applications, including **secure communication networks, sensitive sensors for biomedical imaging and fundamentally new paradigms of computation.**
  - **Quantum computers** are expected to be able to solve, in a few minutes, problems that are unsolvable by the supercomputers of today and tomorrow.
  - This, in turn, will seed breakthroughs in the design of chemical processes, **new materials**, such as higher temperature superconductors, and new paradigms in **machine learning and artificial intelligence**.
  - Quantum technologies will also give rise to **simulation techniques** well beyond current capabilities for material and chemical synthesis, and to **clocks and sensors with unprecedented sensitivity and accuracy**, with potential impact in navigation, the tracking of financial transactions and medical diagnostics.



Top: Low temperature dilution refrigerator (<5mK) with experiments for superconducting qubits as the basis for quantum computers. L. DiCarlo, QuTech, Delft.

Bottom: A segmented chip trap for ion quantum computing and simulation. R.Blatt, IQOQI Innsbruck.

How is “technology fusion” changing industrial policy among the OECD countries?

- Technology fusion in new technology systems is **risky** and requires major **interdependent investment commitments**
- **R&D** is becoming increasingly **dependent on** multiple players from **different science and engineering domains/bases**
- **Technology system scaling-up** is made even more difficult by the **different readiness of emerging technologies (TRLs)** (e.g. multi-KETs Pilot lines in EU)
- Increasing interdependencies among complex, dispersed and multi-tiered supply chains and **emergence of bottlenecks in supply chains** (limited readiness of supply chains/business models in capturing emerging technological opportunities)
- **Value creation and capture** from technology fusion and applications is distributed unequally across **multiple sectoral value chain**

How is “technology fusion” changing industrial policy among the OECD countries?

Different strategies for emerging technologies and strategic sectors

Evidence on industrial policy across six OECD countries (1)

Selected countries	Emerging technologies and technology fusion				Strategic sectors
	Digital tech (ICT, IoT, M2M)	Biotech	Nanotech	Additive mfg	
Australia	Big data, cloud computing & IoT Quantum computing Cyber security	Biotechnologies	Quantum tech		Gas Mining services Medical devices Pharmaceuticals Food processing Agriculture
France	Big data, cloud computing & IoT Embedded software and systems Energy storage Digital Healthcare Industrial plant of the future Augmented reality Robotics Supercomputers Cybersecurity Driver-less vehicles	Plant-based proteins Plant-based chemistry Nano-biotech Bio-informatics Medical biotech Green materials, chemical and biofuels Metals recycling	Nano-electronics Energy storage Electric planes	Additive manufacturing (3D printing)	Healthcare & Personalised medicine Medical device Silver economy Smart textile Smart grids Thermal renovation of buildings Renewable energies Environmental friendly ships Universal cars Heavy-lift airships High-speed train Universal cars

Evidence on industrial policy across six OECD countries (2)

Selected countries	Emerging technologies and technology fusion				Strategic sectors
	Digital tech (ICT, IoT, M2M)	Biotech	Nanotech	Additive mfg	
Germany	Advanced manufacturing systems (Industry 4.0) Big data, cloud computing & IoT Digital networking ICT for electric mobility IT security Autonomics	Bio-economy Advanced & functional materials	Microelectronics Energy storage	Additive manufacturing (3D printing)	Mechanical engineering Energy and renewables Bio-economy Sustainable agriculture Health Intelligent mobility Electric cars Buildings and city of the future
Japan	Big data, cloud computing & IoT Sensors and human interface Robotics Ecological IT equipment	Innovative pharmaceuticals	Nano-technologies		Agriculture, forestry & fisheries Medical care Robotics Energy beyond nuclear Smart mobility Creative industries

Evidence on industrial policy across six OECD countries (3)

Selected countries	Emerging technologies and technology fusion				Strategic sectors
	Digital tech (ICT, IoT, M2M)	Biotech	Nanotech	Additive mfg	
Netherlands	Big data, cloud computing & IoT Smart industry	Advanced & functional materials Regenerative medicine	Nanotechnologies Advanced & functional materials Quantum tech		Personalised medicine Life sciences Agro & food Horticulture Logistics Water Creative industries Smart cities
UK	Big data and knowledge based automation IoT Sensors Energy efficient computing Satellites & space applications Robotics & autonomous systems Energy storage	Biotechnologies Advanced & functional materials Synthetic biology Graphene Regenerative medicine Agri-science	Nanotechnologies Advanced & functional materials Quantum tech Energy storage	Additive manufacturing (3D printing)	Aerospace Automotive Life Sciences International Education Business services Information economy Creative industries Construction Agriculture tech Oil and Gas Nuclear Off-shore wind

Evidence on industrial policy across six OECD countries

- All governments have given **priority to digital technologies** underpinning both existing information and communication systems, as well as the emerging big data, cloud computing and internet of things.
- The emergence of these pervasive digital networks has also pushed the digital frontier in computing, leading to public investments in supercomputers and quantum computing in Australia and France.
- Germany, France and the UK targeted energy and ecological IT equipment, digital healthcare, electric mobility and driver-less vehicles, satellites and space, cybersecurity. More critically, Germany in primis, but also France, Japan and the UK have focused on the development of emerging digital technologies for advanced manufacturing systems.
- In particular, **the integration of digital technologies and networks with robotics and autonomous systems, has led governments to prioritise investments in key technology sub-systems and components, including automation and M2M technologies, embedded software, sensors and human interface, augmented reality.**
- Another related-technology priority in the context of future production technologies and systems is the application of 3D printing and more broadly additive manufacturing (especially in France and the UK)

Evidence on industrial policy across six OECD countries

- All governments have prioritised a **combination of more traditional sectors** – agriculture, agro-food and construction – and their innovative industrial renewal – smart textile for example.
- **Advanced manufacturing, business service and infrastructure sectors, however, tend to play a more prominent role**. Among the targeted high-value manufacturing sectors we can find **aerospace, automotive, mechanical engineering, robotics, medical device and personalised medicine, life science and pharmaceuticals**.
- **Business services** are often related to these manufacturing sectors and the information economy, but also include others such as education in the UK, logistics in the Netherlands and creative industries in Japan and the UK.
- France, Germany and Japan are at the forefront of targeted **investments in energy production and storage, off-shore wind, renewables, environmental-friendly mobility, thermal renovation of buildings, and smart grids.**
- **Oil and Gas as well as Nuclear** are main targets in the UK and Australia, while Japan targeted energy beyond nuclear.

How industrial policies are building **new "industrial ecosystems"** in the OECD countries?

Ind Ecosystem **Emerg Techs**	***Sector 1***	***Sector 2***	***Sector i***	***Sector n***
Digital tech				
Advanced Materials				
Biotech				
Nanotech				
...				

Technology fusion

How industrial policies are building **new "industrial ecosystems"** in the OECD countries?

Ind Ecosystem **Emerg Techs**	***Sector 1***	***New Sectors sectoral applications***	***Sector 2***	***Sector i***	***Sector n***
Digital tech					
Quantum tech					
Advanced Materials					
Biotech					
Nanotech					
…					

Discussion

- The comparative analysis reveal **both similarities and differences** across the OECD countries, **with respect to the strategic sectors (or better sectoral value chains) and emerging technologies they have targeted** and, thus, the different national industrial ecosystems they are building.
- For example, while the problems of **'creating markets' and 'picking technologies'** are central for emerging technologies, **dealing with international competition and upgrading the production processes** are critical in boosting more traditional sectors.
- In unbalanced economies dramatically affected by de-industrialisation (e.g. the UK), rebuilding production capabilities and restructuring local production systems and supply chains appear as critical **pre-conditions for creating and capturing value from technology fusion innovation opportunities**

Discussion

- Industrial policy is becoming increasingly concerned with **operating at the interfaces of the industrial ecosystem** (the interfaces between different industries and/or technologies within the industrial ecosystem)

- **Policy alignment and coordination become even more critical**, although it is also more difficult given the increasing interdependecies among technologies, sectors, activities and organisations (e.g. are sectoral councils still effective?)

- Need for **rethinking the political economy of industrial policy and how interest groups are configured**, but also how incentives, value creation/capture opportunities are regulated and affected by different industrial policy instruments.