

Economies of Scale and Network Economies in Industry 4.0*

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Abstract

Industry 4.0 helps obtain better economic results in mass production and others that support new production models: mass customization and mass personalization. This paper is of a theoretical nature and identifies certain reflections concerning Industry 4.0's role in managerial literature by providing interesting lines to be developed in future directions of research.

Keyword: Industry 4.0; Fourth Industrial Revolution; Enabling Technologies; Economies of Scale; Network Economies; Global Competition

1. Industry 4.0: roadmap

There are usually four phases of technological evolution in the processes of industrial production. The first three industrial revolutions took around two centuries and were the result of: (1) the introduction of water and steam powered machinery in factories (end of the 18th century); (2) the use of mass production technologies, electricity and division of labour (early 20th century); (3) the use of electronics and IT to support automated production (end of the 20th century).

The Fourth industrial revolution however is incorporating industrial automation systems into entire supply chains and product life cycles (early 21th century).

Governments worldwide have realised the importance of the new generation of manufacturing and are active in initiatives including raising awareness, action plan, support, investment in infrastructure, sponsorship, tax benefits – in order to facilitate its implementation into local businesses. These industrial plans deserve particular attention: ‘Advanced Manufacturing Partnership’ in United State (Rafael et al., 2014); ‘High-Tech Strategy 2020’ in Germany (Kagermann et al., 2013); ‘La Nouvelle France Industrielle’ in France (Conseil National de l’Industrie, 2013); ‘Future of Manufacturing’ in United Kingdom (Foresight, 2013); ‘Made in China 2025’ (Li, 2015); ‘Super Smart Society’ in Japan (Cabinet Office, 2015); ‘Research, Innovation and Enterprise’ in Singapore (National Research Foundation, 2016) ‘Innovation in Manufacturing 3.0’ in South Korea (Kang et al., 2016); ‘Il piano Industria 4.0’ in Italy (Ministero dello Sviluppo Economico, 2017).

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In addition to industrial plans, research programmes have been launched in order to develop studies into new enabling technologies designed: by companies and/or private organisations, i.e. ‘Industrial Internet Consortium’ (Evans & Annunziata, 2012); or with public-private partnerships, i.e. ‘Factories of the Future – Horizon 2020 programme’ (European Commission, 2016).

The Fourth industrial revolution has seen rapid growth over the last few years, which has been accompanied by an exponential increase in literature on the many enabling technologies – especially engineering. However, there are still very few management studies that tackle the issue of possible economic benefits for companies manufacturing goods and/or services (products) thanks to the new opportunities on offer.

This theoretical paper looks closely at how the role of the Industry 4.0 is changing the economies of scale, network economies and, more generally, all those factors that amount to the cost differentials.

This work takes from a literature review published in *ISI-Thompson web of science*. The research was conducted using the key words: *Industry 4.0, Fourth industrial revolution, 4th industrial revolution*. Over 2,600 works were found, but only subsequently selected if they had been published in English and in the relevant sector’s top-ranking journals or associated with leading international scientific conferences. They analyse the role of Industry 4.0’s enabling technologies and their influence over the cost differentials (more or less 100 papers).

This paper is organised into five paragraphs. The second describes the very beginning and definition of the term Industry 4.0. The third analyses the key factors and enabling technologies. The fourth outlines the economies of scale, the network economies and more generally the cost differentials. The conclusions provide some reflections and ideas for future directions of research.

2. Industry 4.0: Origins and Definition

The term Fourth industrial revolution was first introduced in 1988 to identify those processes that turn invention into innovation thanks to scientists being included in production teams (Rostow, 1988). The term was later associated with the concept of developing and applying nanotechnologies (Parthasarathi & Thilagavathi, 2011; Hung and 2012). After 2012, the term Fourth industrial revolution lost ground to: Industrial Internet or Advanced Manufacturing (US), Factories of the Future (European Commission), Future of Manufacturing (UK), even though Industry 4.0 is still the most used. Its name comes from the German economy’s development plan (Industrie 4.0, Kagermann et al., 2013).

No conceptual or operative definition of Industry 4.0 has currently been identified and universally recognised. This is due to: its numerous enabling technologies – more than 1200 technologies are estimated (Chiariello et al., 2018); Several enabling technologies (over 1200, Chiarello et al., 2018; 10 macro-categories, Gerbert et al., 2015); rapid obsolescence of innovations; variety of application domains (smart factories, smart cities...); different fields of analysis (engineering, information technology, economics, management...); and different needs of the stakeholders involved (in primis, policy makers, entrepreneurs, academics).

Analysing the literature (Tab. 1) helps determine some shared elements (automation systems, interconnection between physical world and virtual world, identification of a set of enabling technologies, change in the relationships and in

the management) and arrive at a wider definition of the phenomenon. The term Industry 4.0 means adopting industrial automation systems into an entire supply chain and product life cycle.

Table 1: *Industry 4.0's Main Definitions and Enabling Factors*

Author	Year	Definitions and enabling factors
Kagermann & Helbig	2013	Industry 4.0 is a new level of value chain organization and management across the lifecycle of products.
Drath & Horch	2014	Industrie 4.0 is the application of the generic concept of Cyber Physical Systems (CPS) to industrial production systems (Cyber Physical Production Systems, CPPS). Industrial Internet (US) is very similar to Industrie 4.0 but the application is broader than industrial production and also includes e.g. smart electrical grids.
Kube & Rinn	2014	The Industry 4.0 concept is based on the idea of bringing the world of machines together with the Internet, it's the autonomous communication of the workpieces with the machine tools.
Varghese & Denyer	2014	The aim of industry 4.0 is to interconnect and computerize the traditional industries in order to improve the adaptability, resource efficiency as well as the improved integration of supply and demand processes between the factories through machine to machine (M2M) communication.
Bagheri et. al.	2015	The industry 4.0 is a term introduced by Siemens and refers to the integration of interconnected systems into the industry and is known as the fourth industrial revolution.
Baur & Wee	2015	We define Industry 4.0 as the next phase in the digitization of the manufacturing sector, driven by four disruptions: the astonishing rise in data volumes, computational power, and connectivity, especially new low-power wide-area networks; the emergence of analytics and business-intelligence capabilities; new forms of human-machine interaction such as touch interfaces and augmented-reality systems; and improvements in transferring digital instructions to the physical world, such as advanced robotics and 3D printing.
Boston Consulting Group	2015	Industry 4.0 is a transformation that is powered by nine fundamental technology advances: additive manufacturing, augmented reality, big data analytics, autonomous robots, simulation, horizontal and vertical integration, industrial internet of things, cybersecurity, cloud.
Li et al.	2015	Industrial wireless networks (IWNs) are the key technology enabling the deployment of Industry 4.0. New information and communication technologies (ICTs), such as the industrial cloud, big data, wireless cloud networks, internet of things and high performance embedded systems have been introduced into the manufacturing industry to meet the demands for higher productivity, green production, higher market share and flexibility.
Lukač	2015	Industry 4.0 transfers the principles of the Internet of Things on the processing industry. The name Industry 4.0 should express the fourth industrial revolution. Basis for of Industry 4.0 build objects, which are equipped with sensors and intelligent control units as for example, machines, plants or products, which are able to communicate coactive and are able to independently exchange information among each other or with higher level software platforms. These production units are called Cyber Physical System (CPS).
Posada et al.	2015	In the USA, the so called "Industrial Internet - the Third Wave" term coined by General Electric has a strong focus on a higher degree of intelligence with the power of advanced computing, analytics, low-cost sensing and new levels of connectivity permitted by the Internet. Three elements characterize this vision: (i) intelligent machines, (ii) advanced analytics, and (iii) people

		at work. On the other side, the strategic initiative Industrie 4.0 has created not only a German wide but an international landmark in terms of setting the vision, technological opportunities and scientific challenges, related with the entrance of the new generation of ICT technologies, including the Internet of Things and Services and the Cyber-Physical Systems (or CPS), in industrial production systems.
Zhou et al.	2015	Industry 4.0 encapsulates future industry development trends to achieve more intelligent manufacturing processes, including reliance on Cyber Physical Systems (CPS), construction of Cyber-Physical Production Systems (CPPS), and implementation and operation of smart factories.
Hermann et al.	2016	Industry 4.0 is a collective term for technologies and concepts of value chain organization.
Vogel-Heuser and Hess	2016	Industry 4.0 – derived from the German term Industrie 4.0 – is used as a synonym for Cyber-Physical Production Systems (CPPS) applied in the domain of manufacturing/production. [...] There are still several definitions of Industrie 4.0. Most of them agree on the following design principles: service orientation; interoperability; virtualization; real time capability; cross-disciplinary modularity; etc.
Siemens	2017	Industry 4.0 introduces the digitalization of processes, the Internet of Things, the installation of widespread sensors in the physical environment and the ability to rapidly enhance production economics through real-time performance-data analysis.

Source: own production

3. Industry 4.0: Key Factors, Enabling Technologies and Competitive Advantages

The two key factors for Industry 4.0's success are: *integration* and *interoperability* (Lu, 2017).

Integrating industrial automation systems – Cyber Physical System (CPS) and Cyber Physical Production System (CPPS) – results in greater and more innovative features via networking with stakeholders (both horizontally and vertically). It also helps create connection between cyber world and physical world.

Interoperability in fact facilitates production processes, even without continuity, within and beyond the confines of a business thanks to interconnecting systems and exchanges of know-how and skills.

Industry 4.0 uses a series of enabling technologies which can be categorised into ten dimensions. These categories come from a studio by the Boston Consulting Group (Gerbert et al., 2015) and some Authors (Wan et al., 2015; Kinsy et al., 2011) add an other category '*Others enabling technologies*'.

1. *Advanced manufacturing solution*, creating interconnected and modular systems that guarantee the automation, efficiency and – at the same time - reduction in labour costs and improvement of work conditions. This is especially the case for companies using easily degradable and/or dangerous materials. These technologies include systems for automatic handling materials and advanced robotics that is present in today's market with Cobot (collaborative robots) as well as Automated guided vehicles.
2. *Augmented reality*, creating systems that support operators with: daily tasks, solving problems of malfunctioning machinery and virtual training. A prime example could be Augmented-reality glasses.

3. *Internet of things*, introducing sets of devices and intelligent sensors that facilitate communication between various elements of production, not only inside a company but also beyond its confines thanks to the internet. These technologies allow for decisional processes to be decentralised, answers to problems given in real time and customised services created for clients via apps.
4. *Big data analytics*, having large quantities of data and analytical tools (simulation) that optimise products and decisional processes of the different productive parts of a value chain. The benefits of using big data are: understanding demand through studying client portfolios and scenarios; identifying changes to the benefits the client asks for; optimising the supply chain, improving efficiency in the warehouse, distribution and sales; containing production costs; reducing energy consumption, supported by seeing anomalies automatically in real time.
5. *Cloud computing*, implementing technologies that facilitate better performance in archiving and processing information in terms of speed, flexibility and efficiency.
6. *Cyber-security*, those security measures designed to protect information flows that can be exchanged via interconnected company systems.
7. *Additive manufacturing (i.e. 3D printing)*, applying systems that give assurance: faster complex planning and prototyping phase; production of small lots of customised production with advantages in terms of lower production costs and reduction of stock.
8. *Simulation*, acquiring materials, products and productive processes through introducing devices able to reproduce the physical world into virtual models with benefits in the diverse phases of product design and fine tuning productive processes.
9. *Horizontal e vertical integration*, integrating and exchanging information in the supply chain, production chain and all the other stakeholders (i.e. suppliers, clients, industrial partners, sales reps, research and development centres). These systems help companies acquire: independence in collecting and analysing internal and external information in order to plan decisions; ability to self-study and identify, diagnose and solve problems; better connections of the supply chain. Applications identified are: Information facilities systems, Information application systems, Equipment management system and Public safety system.
10. *Others enabling technologies*, these are technologies used for specific fields (see agrifood, bio-based economy, ...) and tools that determine where, when and how energy resources are used with the aim of eliminating or reducing waste.

In the Industry 4.0, the focus is based on the environment of communication and relationships between people, places, things and machines, realized thanks to CPS and CPPS. This environment allows to get flexible routine for the development of products and processes useful to improve quality of work, social and environmental sustainability (Freeman & Dmytiryec, 2017; Mosca & Civera, 2017; Büchi & Cerruti, 2018). In addition, this communication platform allows to get the global competitiveness benefits overcoming the limits of spatial proximity thanks to the creation of global digital ecosystems (Brondoni, 2018).

Literature, thanks to laboratory experiments or case studies, shows that benefits can be acquired by adopting just one of the enabling technologies, even though it's more advantageous to apply more innovations during the various phases of the value chain (Vogel-Heuser & Hess, 2016).

4. Industry 4.0: Economies of Scale and Network Economies

From an economic-financial point of view, a business takes on new fixed costs for purchasing the technologies when it adopts Industry 4.0, although these costs can change according to industrial plans. The purchase cost means a company will subsequently benefit from a reduction of variable costs and consequently average unit costs. It is a complex process which could potentially involve activating measurable economic factors in terms of lower costs and/or higher turnover achievable over time.

Three co-existing scenarios can be obtained, depending on the enabling technologies adopted.

Scenario i) Under the hypothesis of *mass production* model adoption and of a constant turnover ($T_A=T_B=T_C$), the economic benefits of Industry 4.0 are initially found in improvements in the supply chain thanks to economic factors based on a company's costs, e.g.:

- economies of scale (technological), following technical efficiency;
- economies of scale (managerial), linked to automated logistic and administrative processes;
- economies of learning and experience generated by training operators, automation and integrating processes;
- network economies made possible by greater interconnection between companies and value systems on a global scale;
- economies of aim that are followed by the creation of new products at low or zero cost of change.

The company can decide to use a traditional method (level of average total cost A) or use one or more Industry 4.0 enabling technologies (level of average unit cost C), where purchase costs can be reduced with industrial plan incentives (level of average unit cost B). Levels of average unit costs A, B, C correspond to a fixed cost (CF) gradually higher ($FC_A < FC_B < FC_C$) but, at the same time, determine a reduction in variable unit costs ($VC_A > VC_B > VC_C$) thanks to the efficiency produced by the innovation of Industry 4.0.

Industry 4.0 enabling technologies support *mass production*, by creating *mass customization* (or *smart manufacturing*) and *mass personalization* (*additive manufacturing* or *smart factory*) (Yao and Ying, 2016). This goes from a production model based on the manufacture of large unique standardised products with limited varieties of products to models that create two other scenarios.

Scenario ii) Manufacturing products to satisfy the needs of single clients with production efficiency near *mass production* and limited volumes – compared to *scenario i)* (*mass customization*), (Fogliatto et al., 2012; Tseng & Jiao, 2001).

Scenario iii) Manufacturing products and purchasing experience for individual consumer tastes based on their preferences and with defined volumes – compared to *scenarios i)* and *ii)* (*mass personalization*) (Tseng, Jiao & Wang, 2010; Chellappa & Sin, 2005).

Mass customization and *mass personalization* help implement a varied product range – from *many of a kind* to *one of a kind* – which can then be adapted as demand changes over time, leading to further reductions of average unit costs.

Anderson (2014 and 2016) defines this way of working as similar to the expression *long tail strategy* that guarantees companies can make a profit from selling small volumes of customised products that are difficult to find on the market instead of large volumes of mass products (Brynjolfsson et al., 2010). Comparable situations can be seen by producing small lots (niche) thanks to *additive manufacturing* (Shapeways, 2015), that offers products on-demand using 3D printing.

Mass customization and *mass personalization* offer both economies of scale (increase in turnover) and economies of scope (savings in cost following greater variety of products) by way of the so-called *ideal production system* (Koomsap, 2013). *Mass customization* and *mass personalization* offer faster response time to the changes in the demand and to the over-demand and over-supply (Brondoni, 2005), reduce the problem of products staying in the warehouse and improve ability to forecast demand, create greater involvement when identifying client needs and leads to faster production.

Therefore it is advantageous to create “tailored” solutions which match the three scenarios that can be adopted flexibly over time in order to maximise profit. We should remember that

$$\begin{aligned}\text{Profit} &= \text{turnover} - \text{production costs} + \text{incentives} = \\ &= \text{turnover} - \text{variable costs} - \text{fixed costs} + \text{incentives}\end{aligned}$$

Let's imagine a simple formula where every production schedule corresponds to one single product, yearly profit would be maximised (t) i.e.:

$$\text{Max}(\Pi_t) = (p_1q_{1t} + p_2q_{2t} + p_3q_{3t}) - [(FC_{1t} + FC_{2t} + FC_{3t}) + (VC_{1t}q_{1t} + VC_{2t}q_{2t} + VC_{3t}q_{3t})] + \alpha_t$$

where

Π = profits at time t

t = time

FC_t = fixed costs at time t

VC_t = variable unit costs at time t

α_t = government incentives at time t

p_1 = price of product mass production at time t

p_2 = price of product mass customization at time t

p_3 = price of product mass personalization at time t

q_1 = quantity of product mass production at time t

q_2 = quantity of product mass customization at time t

q_3 = quantity of product mass personalization at time t

In mathematical terms, this happens when the first derivate of the total cost (marginal cost net of incentives) is equal to the first derivate of the total earnings (marginal earnings) compared to the quantity of production (q).

5. Early Reflections and Future Lines of Research

The theoretical analysis shows that the Industry 4.0 provides significant potential by bringing communication, interconnection and relationships environment between people, places, things and machines. It also demands drastic rethinking and change regarding government and strategic and operative management.

This paper does not claim to be exhaustive in its treatment of this subject due to its magnitude and variety of sub-topics, but it intends to shed a critical light on enabling economies of the Industry 4.0's automation systems.

The results outline that companies get a flexible production system choosing between seven combinations of the different productive scenarios:

- (1) *mass production*;
- (2) *mass customization*;
- (3) *mass personalization*;
- (4) *mass production and mass customization*;
- (5) *mass production and mass personalization*;
- (6) *mass customization and mass personalization*;
- (7) *mass production, mass customization and mass personalization*.

This strategic and operative choice depends on the necessity to be flexible - even for limited periods of time - to respond to different demand and supply levels and quality efficiency and productivity standards working with an advanced lean production.

Optimising productive capacity guarantees higher economies of scale (augmented production capability), higher scope economies (augmented products variety), and higher network economies (augmented interconnection between stakeholders).

From an economic point of view, this cost differentials are evaluated in terms of lower costs and higher income and consequently, greater profit.

In light of these considerations, an empirical investigation has become urgent concerning cross-section analysis of firms that can confirm or reject the early reflections about the role of the cost differentials (Büchi, Cugno, Castagnoli, accepted). The relationship must then be explored: if (presence/absence) and to what degree application of enabling technologies is needed to achieve an advantage equal to a series of control variables (business sector, size, type of technologies used...). The economic benefits applying Industry 4.0 can in fact be subject to decreased output that limit or frustrate investments made.

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