Levels of openness to Industry 4.0 and performance

An empirical analysis of manufacturing companies

EXTENDED ABSTRACT

1. *Scope and structure of a extended abstract*

This work is part of a line of study into a company's economic benefits and competitiveness by analysing the relationship between its performance and its level of openness towards Industry 4.0's enabling technologies. The level of openness has been investigated using two indicators: breadth (number of enabling technologies used) and depth (number of environments for application in the Industry 4.0 supply chain). Performance has been measured by the economic benefits that the company obtains. This study comprises a practical analysis carried out in 2018 based on a sample representative of local businesses in the manufacturing sector in Piedmont (North Italy).

The extended abstract is explained in five sections. The second section is a critical analysis of literature about Industry 4.0 and identifies research theories. The third section describes the data-base, the variables and the econometric model used. The fourth section goes into further detail about the main practical results. The fifth section outlines the discussion of the results. The work then rounds up with conclusions and options for future projects.

2. Theoretical background and lines of research

Industry 4.0 is a controversial process due to its origins, definition and enabling technologies necessary for its implementation; as well as the economic benefits that can be derived from it.

Literature does not provide a universally accepted, conceptual and practical definition of Industry 4.0 due to the numerous enabling technologies that are at its base and the different disciplines that analyse it – engineering, IT, economics, management… It is possible, though, to provide a wider definition. The expression Industry 4.0 means adopting industrial automation systems throughout the entire production chain and product life cycle.

The key factors are: integration and interoperability (Lu, 2017). Integrating industrial automation systems – Cyber Physical System (CPS) and Cyber Physical Production System (CPPS) – leads to greater innovative functions thanks to networking among stakeholders (both horizontally and vertically) as well as facilitating connections between physical operations and IT and communication infrastructures. Interoperability, on the other hand, allows for setting up_systems, even without the continuity of solution, beyond a company's walls thanks to interconnected systems and exchange of knowledge and skills.

Industry 4.0 uses a series of enabling technologies that can be categorised in ten dimensions (Fig. 1). This classification derives from the study by the Boston Consulting Group (Gerbert et al., 2015) that recognises the first nine enabling technologies and which certain authors (Wanet et al., 2011) match to yet another dimension with more across-the-board characteristics and linked to the reduction/containment of energy consumption.

Each enabling technology provides a series of economic benefits (Fig. 1).

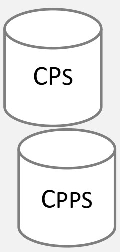
However, Vogel-Heuser & Hess (2016) show that applying more than one Industry 4.0 enabling technology to the various phases of the production line and/or supply chain is advisable in order to obtain a greater advantage.

We can therefore assume the following research HP:

HP 1 Breadth helps companies obtain greater benefits when applying Industry 4.0 enabling technologies.

HP 2 Depth helps companies obtain greater benefits when applying Industry 4.0 enabling technologies.

Fig. 1 Industry 4.0: enabling technologies and benefits



	Enabling technologies	Benefits
①	*Advanced manufacturing solution*	Automation, efficiency, reduction in labour costs and improvement of work conditions
②	*Augmented reality*	Solving problems malfunctioning machinery and virtual training
③	*Internet of things*	The decisional processes to be decentralised, answers to problems given in real time and customised services created for clients via apps
④	*Big data analytics*	Understanding demand; 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*	Better performance in archiving and processing information in terms of speed, flexibility and efficiency
⑥	*Cyber-security*	protect information flows
⑦	*Additive manufacturing*	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*	Benefits in the diverse phases of product design and fine tuning productive processes
⑨	*Horizontal e vertical integration*	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
⑩	*Technologies supporting the optimisation of energy consumption*	To determine who, where, when and how energy resources are used with the aim of eliminating or reducing waste

The literature (Büchi, Cugno & Castagnoli, *submitted*) sheds light on how Industry 4.0 provides enabling technologies that help companies achieve greater advantages following greater efficiency (*Scenario i*) and increased production capacity (*Scenarios ii* and *iii*).

Scenario i) This ranges from a production model based only on manufacturing large quantities of standardised products with limited variety of products (*mass production*) with greater efficiency (measured in terms of higher earnings and lower costs) to models that include two other production scenarios.

Scenario ii) Manufacturing products in order to satisfy each individual client's needs with production efficiency near mass production but in limited numbers (*mass customization*) (Fogliatto, da Silvera, & Borenstein, 2012; Tseng & Jiao, 2001).

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

M*ass customization* and *mass personalization* facilitate implementing a variety into the product range – going from the *many of a kind* variety to a *one of a kind* variety. This can then be altered over time in response to growing needs for variety that demand calls for and consequently result in further lowering of average unit costs.

Anderson (2014 and 2016) defines this method by using the expression *long tail strategy* which guarantees companies will make a profit by selling small volumes of customised products that are difficult to find on the market, instead of only selling large volumes of mass produced products (Brynjolfsson, Hu & Smith, 2010). Similar situations have arisen from manufacturing small lots (*niche*) thanks to *additive manufacturing* (Shapeways, 2015), that offers on-demand products via 3D printing.

This literature maintains that smaller – unlike larger – businesses are excluded by the mass production model from obtaining economies of scale and networking, but should obtain greater benefits by adopting enabling technologies. This is because they can - even temporarily - adapt their production capacity to emerging market needs, time to market, efficiency and productivity quality standards.

We can then assume:

HP 3 – Small companies obtain greater benefits by applying Industry 4.0 compared to larger ones.

Economic-managerial literature about innovation (Cohen & Levinthal, 1999) and open innovation (Lauren & Salter, 2006) practically confirms that the relationship between being open to innovation and performance takes on an inverted U-shape function, ie a point exists which creates diseconomies/disadvantages in applying further innovation - should a company go beyond it.

We can then assume two research HPs:

HP 4 – The breadth of applying Industry 4.0 enabling technologies is curvilinear e takes on an inverted U-shape.

HP 5 – The depth of applying Industry 4.0 enabling technologies is curvilinear and takes on an inverted U-shape.

3. Research methodology

3.1 Sample

This data comes from the report *Congiuntura Industriale in Piemonte* (North-Italy) which was carried out in 2018 on a sample representative of local businesses in the manufacturing sector in Piedmont and featuring at least two operators from the different size groups and different product sectors. The questionnaire collects information on companies' structural and economic characteristics and the Industry 4.0 enabling technologies they had implemented.

3.2 Econometric measures and model

The relationship that links performance (Y dependent variable) to a dependent variable set and control is estimated using different models of linear regression with the minimum square method.

Dependent variables

Managerial literature (section 2) shows how implementing Industry 4.0 enabling technologies leads to a company obtaining economic benefits mostly linked to: production flexibility (thanks to manufacturing small lots); speed of serial prototypes; greater output capacity; reduced set-up costs and fewer errors and machine stoppages; higher product quality and less production rejects; clients' better opinion of products.

Variable performance (P) consists of the sum of the six variables of economic benefits where each variable is coded as a dummy variable (0 no benefit; 1 perceived benefit). The six dummies were then summed up in order to obtain an indicator of use, from and including 0 (no benefit) to six (substantial benefits of using Industry 4.0).

Independent and control variables

The level of openness towards Industry 4.0 is assessed through the BREADTH and DEPTH variables by using enabling technologies.

BREADTH comprises the combination of the ten variables of the enabling technologies (Fig. 1). Each variable is coded as a dummy variable (0 not implemented; 1 implemented). The 10 dummies were then summed up in order to obtain an indicator of implementation of Industry 4.0, including between one (when just one of the technologies was adopted) to 10 (if all the technologies were implemented).

DEPTH acts as a measure for companies to use Industry 4.0 enabling technologies intensely throughout the supply chain. DEPTH is made up of the same ten enabling technologies (as in the previous case), but in this case, each of the ten technologies is coded as a dummy variable (0 not used or rarely used; 1 frequent use of Industry 4.0 in the supply chain). Once again, the ten dummies were then summed up in order to obtain an indicator of use, from and including 0 (when there is little implementation of enabling technologies) to 10 (frequent use of Industry 4.0).

The model uses the following control variables.

- Four variables assess the size of business based on the number of employees (SIZE -micro, -small, -medium, -large).
- Eight variables measure the influence of the economic sectors, subsequently transformed into HIGH variable to only consider the sectors with higher technological content (dummy).
- One variable OPEN-ET considers if companies are inclined to further implement their enabling technologies portfolio (dummy).

4. Main results

4.1 Descriptive analysis

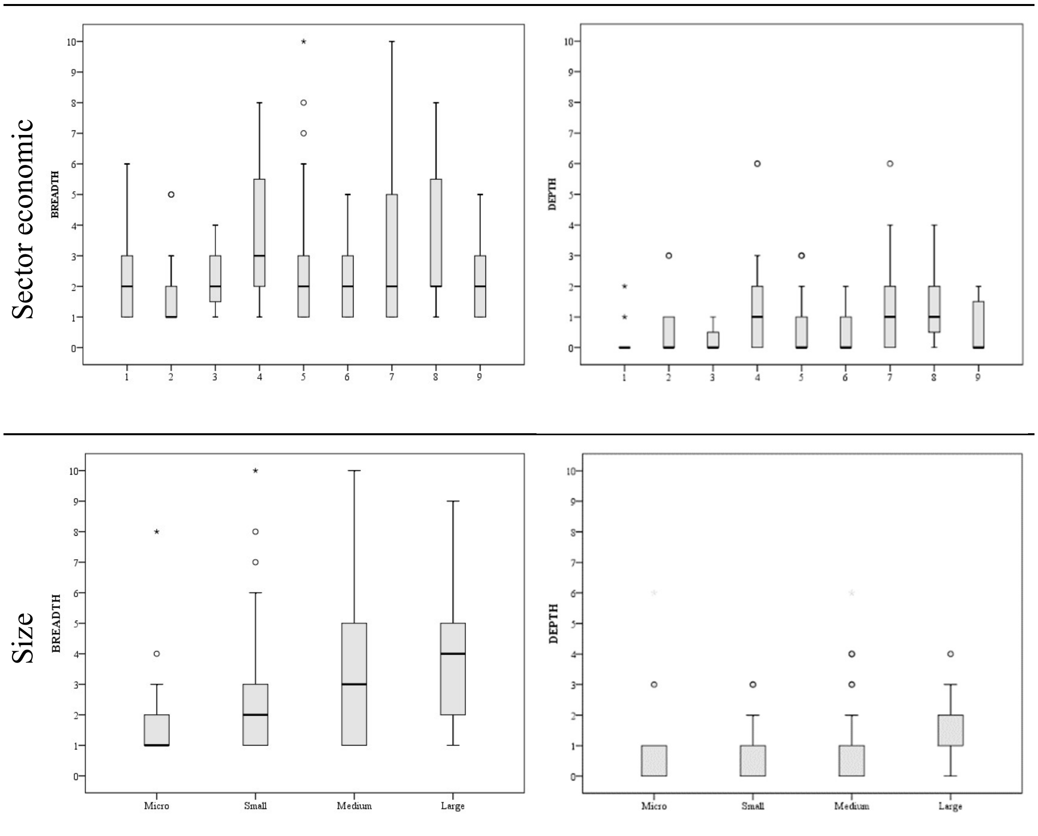
Implementation of Industry 4.0 (Tab. 1) is still very limited by: percentage of companies adopting an enabling technology (just 15.1% of the sample); number of technologies adopted (BREADTH mean=2.7); depth of their use in the supply chain (DEPTH mean=1).

Tab. 1 Main indicators of Industry 4.0

	Variable	N. LU	% LU Industry 4.0	LU Industry 4.0 (n=231)	
				Breadth mean	Depth mean
Economic sector	1. Food	164	7.9	2.6	.2
	2. Fabrics, clothing and footwear	180	11.7	1.8	.6
	3. Wood and furniture	59	5.1	2.3	.3
	4. Chemical, petroleum and plastic materials	121	23.1	3.5	1.3
	5. Metals	294	15.3	2.5	.5
	6. Electronics	102	17.6	2.2	.5
	7. Mechanical	208	23.6	3.1	1.1
	8. Means of transport	61	19.7	3.4	1.5
	9. Other manufacturing sector	142	8.4	2.2	.6
Size	Micro [0-10[	422	5.0	1.8	.7
	Small [10-50[	631	13.6	2.2	.5
	Medium [50-250[	224	32.6	3.2	1
	Large [250 – more	54	38.9	4.3	1.5
Total		1331	–	–	–
Average		–	15.1	2.7	.8

The Industry 4.0 phenomenon is mostly present in the sectors of mechanical and chemical products as well as means of transport and larger companies (medium and large), even though their situations are individually very different due to economic sector and size (Box-plot 1).

Boxplot 1 Breadth and depth (n=231)



4.2 Linear regression

Table 2 shows the results of the relationship between the level of openness and performance. Each column is numbered from (1) to (3) and shows a regression with the introduction of different variables. The table shows the coefficients, standard errors, statistics χ^2 and p-values.

Model (1) confirms the relationship without considering the effect of the control variables, model (2) considers the effects of the control variables and model (3) considers a quadratic variables to regression in the $BREADTH^2$ and $DEPTH^2$ variables.

The three models confirm HP 1, 2 and 3, while HP 4 and 5 cannot be confirmed or rejected due to the not significance level of $BREADTH^2$ and $DEPTH^2$.

Tab. 2 Linear regressions models

Model	(1) Coeff.	S.E.	P-value	(2) Coeff.	S.E.	P-value	(3) Coeff.	S.E.	P-value
BREADTH	.372	.034	***	.124	.035	**	.345	.101	**
DEPTH	.175	.081	*	.192	.064	*	.267	.131	*
Size-micro				1.001	.207	***	.839	.217	***
Size-small				.866	.120	***	.647	.143	**
Size-medium				.766	.149	***	.563	.169	*
HIGH				.236	.123	*	.281	.128	*
OPEN-ET				.375	.126	*	.153	.124	
$BREADTH^2$							-0.28	.012	
$DEPTH^2$							-0.21	.029	
N. obs.		231			231			231	
F		162.672	***		97.746	.000			

Individually, the coefficients are significant level *<5% o **<1% ***<1%@

5. Discussions and conclusions

This study attempts to close the gap in management literature concerning the potential the new industrial revolution offers companies in its creation of value. Its practical approach investigates the relationship between level of openness towards Industry 4.0 and performance.

In its almost exclusively theoretical approach, economic-managerial literature sheds light on the fact that companies that are more open to innovation obtain greater benefits.

Research suggests that the Industry 4.0 phenomenon is limited to a number of companies that use few enabling technologies and that only develop them superficially along the value chain.

Those companies that are more open (measured in terms of numbers of technologies, depth of application along the supply chain and desire to increase their portfolio of technologies in the future) obtain the most benefits. The presence of positive and higher coefficients suggests that smaller companies obtain the greatest benefits.

Innovation research is expensive in terms of time, cost, commitment to obtaining specific knowledge, skills in understanding potential and functioning of the technologies, clients and markets. Investment can only be taken into account in the long term.

6. Limitations and future research

Industry 4.0 is a recent phenomenon which companies have not yet fully embraced, so the results obtained deserve further study to confirm the data panel that assess the benefits obtained over a longer period of time.

Further interesting facts could be obtained by aspects that cannot be investigated with the current data-base.

Promising lines of research have been identified through models that consider the following points to be different:

- dependent variables that measure the impact of applying Industry 4.0 on companies' results (percentage of turnover, improvement in production capacity, increase in employee numbers, lower costs and/or higher earnings);
- non-linear regression models that consider the interaction between independent variables.

References

Anderson C. (2004). The long tail. *Wired Magazine.*

Anderson C. (2006). The long tail: why the future of business is selling less of more. Hachette Books.

Brynjolfsson E., Hu Y.J., & Smith M.D. (2010). The longer tail: the changing shape of Amazon's sales distribution curve. *2009 Workshop on Information Systems and Economics*.

Büchi G., Cugno M., & Castagnoli R. (Submitted). *Economies of scale and network economies in Industry 4.0. Theoretical analysis and future directions of research*.

Chellappa R.K., & Sin R.G. (2005). Personalization versus privacy: an empirical examination of the online consumer's dilemma. *Information Technology and Management*, 6 (2-3), 181-202.

Cohen W.M. (1995). Empirical studies of innovative activity. In Handbook of the *Economics of Innovation and Technological Change*, Stoneman P (ed). Blackwell, Oxford, 342–365

Fogliatto F.S., da Silvera G.J., & Borestein D. (2012). The mass customization decade: an updated review of the literature. *International Journal of Production Economics*, 138 (1), 14-25.

Gerbert P., Lorenz, M., Rüßmann M., Waldner M., Justus J., Engel P., & Harnisch M. (2015). Industry 4.0: The future of Productivity and growth in Manufacturing Industries. *BCG Perspectives*.

Kinsy, M., Khan, O., Ivan, C., Majstorovic, D., Celanovic, N., & Devadas, S. (2011). Time-predictable computer architecture for cyber-physical systems: digital emulation of power electronics systems. *Proceedings of 2011 IEEE 32nd Real-Time Systems Symposium (RTSS)*, 305-316.

Lauresen K. & Salter A., (2005). Open for innovation: the role of openness in explaining innovation performance among U.K. manufacturing firms. *Strategic Management Journal*, 27, 131-150.

Lu, Y. (2017). Industry 4.0: A survey on technologies, applications and open research issues. *Journal of Industrial Information Integration,* (6), 1-10.

Shapeways. (2015). 2015 Shapeways trasparency report. *Shapeways magazine, 3d printing news and innovation.*

Vogel-Heuser, B., & Hess, D. (2016). Guest editorial Industry 4.0 – prerequisites and visions. *IEEE Transactions on Automations Science Engineering*, 13 (2), 411-413.

Wan, J., Cai, H. & Zhou, K. (2015). Industrie 4.0: Enabling Technologies. *International Conference on Intelligent Computing and Internet of Things (ICIST)*.