Finanțat de Uniunea Europeană
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Planul Național de Redresare și Reziliență

The role of innovation ecosystems in the successful implementation of Industry 4.0 technologies

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Agenda

1. Introduction
2. Literature review and hypothesis development
3. Methodology
4. Findings
5. Conclusion

Agenda

Introduction

Manufacturers face significant challenges when implementing I4.0 technologies. While barriers are well explored in the literature, how to overcome these challenges is still an underexplored area of research.

Most frequent I4.0 implementation barriers

- Economic/financial barriers
- Lack of knowledge and human capabilities
- Lack of strategic/managerial vision and awareness
- Need to change leadership and culture
- Proper data management, security and safety
- Technology infrastructure and integration challenges

Knowledge to support overcoming these challenges

Innovation ecosystem as a primary knowledge source:

- Internal ecosystem
- External ecosystem

Recommended research directions:

- Matt et al. (2021) -> extend the scope of innovation ecosystem considering multiple actors for I4.0 implementation
- Ferraso et al. (2018) -> different technology implementation stages might require different ecosystem collaboration

Source: Demeter et al., (2024) (EurOMA Conference), Matt et al. (2021), Ferraso et al. (2018)

Introduction

This paper adopts a knowledge-based perspective arguing that the successful adoption of I4.0 technologies depend on the available sources of knowledge and the manufacturer's ability to recombine them with its existing knowledge base.

Research question	**How does the involvement of internal and external actors of the innovation ecosystem influence the implementation and performance benefits of digital manufacturing technologies at the manufacturing plant level?**
Theoretical relevance	The results provide generalized and nuanced evidence of the different **role of internal and external innovation ecosystems** on the different (**both traditional and I4.0**) digital manufacturing technology **implementation stages**.
Practical relevance	**Which part of the ecosystem** can act as a creative **stimulus to the adoption of digital technologies** and in which **adoption stage** -> improve the **performance impact** of digital technologies in practice.
Data and methodology	Questionnaire survey (Global Manufacturing Research Group (GMRG) survey: www.gmrg.org) (N = 293) + PLS Structural Equation Modelling (SEM)

Source: own construction

Agenda

Literature review

Our paper considers (1) the role of both internal and external innovation ecosystems for (2) both I3.0 and I4.0 technologies (3) during both the idea and the implementation phases.

Innovation ecosystems

Collaborative arrangements between different firms of the ecosystem allows the **focal firm to create value-added** that would have been impossible without such ecosystem collaboration *(Adner, 2006)*.

The evolving set of actors, activities, and artifacts, and the institutions and relations, [...], that are important for the **innovative performance** of an actor or a population of actors *(Granstrand and Holgersson, 2020)*.

Activities create artifacts -> most frequently mentioned artifacts: **knowledge** and **technologies**

KBV – internal and **external innovation ecosystems** help enriching the firm's **knowledge base** *(Gawer and Cusumano, 2013)* to implement new technologies.

Digital manufacturing technologies

Traditional digital technologies (Industry 3.0): e.g., CAM, CAD, CNC, ERP, EDI, Kanban

+

Industry 4.0 technologies (real-time interconnection, predictive and adaptive capabilities): e.g., IoT, BDA, ML/AI, 3D printing, advanced/collaborative robots.

Stages of digital technology adoption:

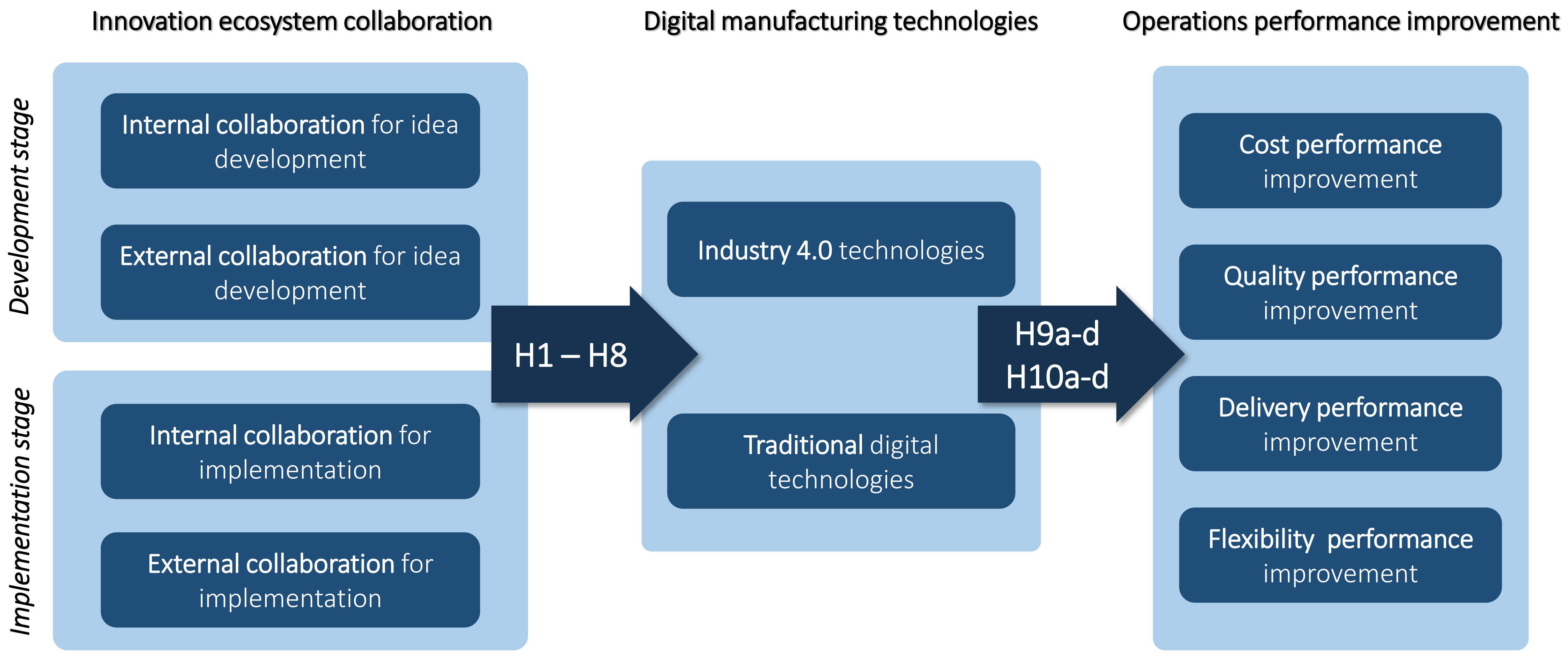
- **Idea phase:** idea generation and elaboration, including technology identification and selection
- **Implementation phase:** bringing technology to production, testing and usage

(Cardoso et al., 2012; Perry-Smith and Manucci, 2017)

Source: own construction based on the articles analysed

Hypothesis development

Hypotheses assume a positive relationship between (1) collaboration with the internal and external innovation, (2) digital manufacturing technologies and (3) operations performance improvement.



Source: own construction

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Variables analysed

The latent variables reflect the content of different indicators that are all emasured on a 7-point Likert scale and refer to the activities and performance of the respondent manufacturing plant in th last 2 years.

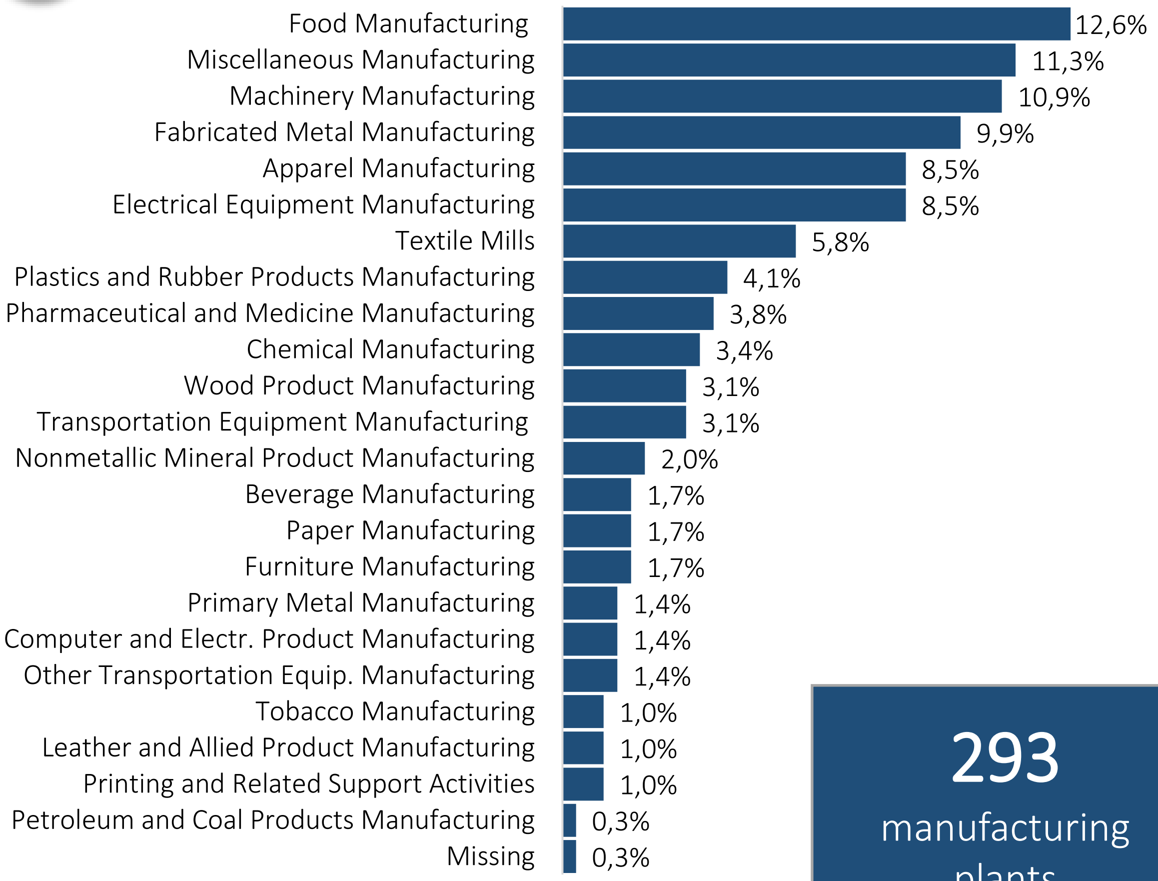
Variable category		Latent variable	Scale	Measurement	Description	Mean	Standard deviation
Innovation ecosystem collaboration	Development stage	Development_internal	Likert-scale (1-7)	Involvement over the last 2 years	Plant operators; Maintenance personnel (i.e., technicians); R&D personnel (i.e., product and process engineers); Sales/marketing; Purchasing/supply management	4,289	1,788
		Development_external	Likert-scale (1-7)	Involvement over the last 2 years	Suppliers; Customers; Research organizations (universities, research centers, etc.); Government and other public institutions; Members of conferences, trade fairs; Consultants	3,187	1,870
	Implementation stage	Implementation_internal	Likert-scale (1-7)	Involvement over the last 2 years	Plant operators; Maintenance personnel (i.e., technicians); R&D personnel (i.e., product and process engineers); Sales/marketing; Purchasing/supply management	4,218	1,870
		Implementation_external	Likert-scale (1-7)	Involvement over the last 2 years	Suppliers; Customers; Research organizations (universities, research centers, etc.); Government and other public institutions; Members of conferences, trade fairs; Consultants	3,049	1,901
Digital manufacturing technologies		Industry 4.0	Likert-scale (1-7)	Investments in the last 2 years	Big Data Analytics; Internet of Things (IoT, 5G); Cloud computing; Machine learning/artificial intelligence; Simulation; Cyber-physical systems; Blockchain; Additive manufacturing / 3D printing; Automated guided vehicles (AGV)/drone; Advanced/collaborative robotics	2,485	1,861
		Traditional digital technologies	Likert-scale (1-7)	Investments in the last 2 years	Computer aided manufacturing/inspection (CAM/CAI); Computer numerical control (CNC); Electronic data interchange (EDI); Enterprise resource planning (ERP); Computer-aided design (CAD); Computer-aided engineering (CAE)	3,749	2,157
Operations performance improvement		Cost	Likert-scale (1-7)	Plant's performance 2 years ago	Labor unit costs; Total product unit costs; Raw material unit costs	3,695	1,537
		Quality	Likert-scale (1-7)	Plant's performance 2 years ago	Product performance; Product conformance to specifications	4,441	1,491
		Delivery	Likert-scale (1-7)	Plant's performance 2 years ago	Delivery speed; Delivery reliability	5,021	1,356
		Flexility	Likert-scale (1-7)	Plant's performance 2 years ago	Production volume flexibility (increase/decrease volume); Production variety flexibility (increase/decrease product mix)	4,798	1,218

Source: own construction

Final research sample by countries. industries and size

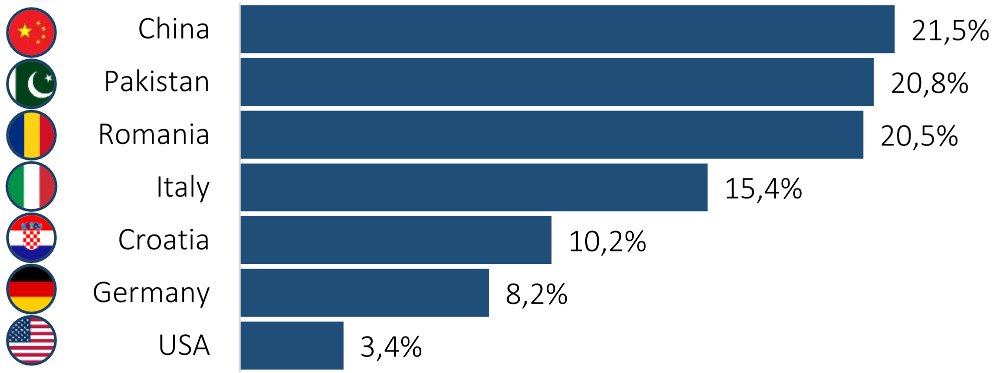
The sixth edition of the Global Manufacturing Research Group (GMRG) survey (www.gmrg.org) is used that comprises useful data on **293 manufacturing plants** from 7 different countries.

Industries

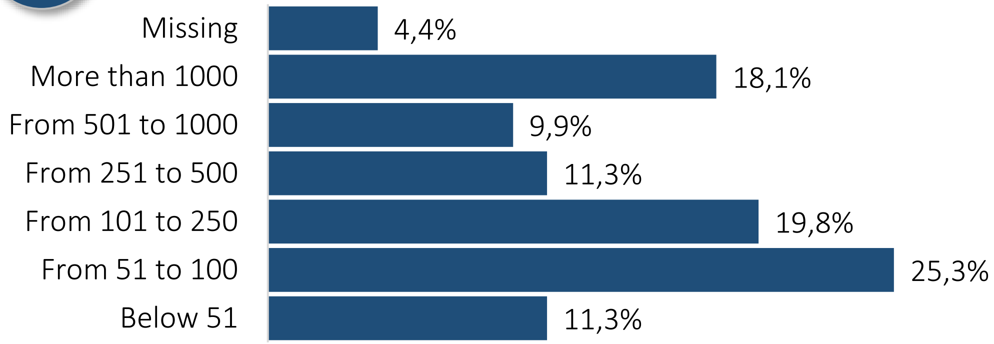


293
manufacturing plants

Countries



Number of employees (size)



Source: own construction

Method

The empirical analysis was based on a questionnaire survey; the methodology used was partial least squares structural equation modeling (PLS-SEM).

- SEM can handle **complex interrelations**;
- is able to sasses **indirect and total effect on the constructs of interest**;
- it can be applied even to **small and medium-sized datasets**;
- the **factor and the regression analysis can be deployed at the same time**. which was necessary in this research. since the main variables were made from different factors;
- can **handle nonnormally distributed data** as well. which is an important feature. because the data from surveys typically shows skewed distribution.

Source: own construction

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Construct reliability and validity

To assess the reliability and the validity scores of our measurement model, we used PLS algorithm. After the assessment of all the necessary indicators, we accepted our outer model.

Construct reliability and validity

			Cronbach's alpha	Composite reliability (rho_c)	Average variance extracted (AVE)
Innovation ecosystem collaboration	Development stage	Development_internal	0.824	0.865	0.567
		Development_external	0.839	0.882	0.561
	Implementation stage	Implementation_internal	0.800	0.835	0.529
		Implementation_external	0.879	0.910	0.632
Digital manufacturing technologies		Industry 4.0	0.947	0.955	0.679
		Traditional digital technologies	0.930	0.945	0.742
Operations performance improvement		Cost	0.821	0.893	0.737
		Quality	0.924	0.963	0.929
		Delivery	0.866	0.924	0.859
		Flexility	0.873	0.933	0.875

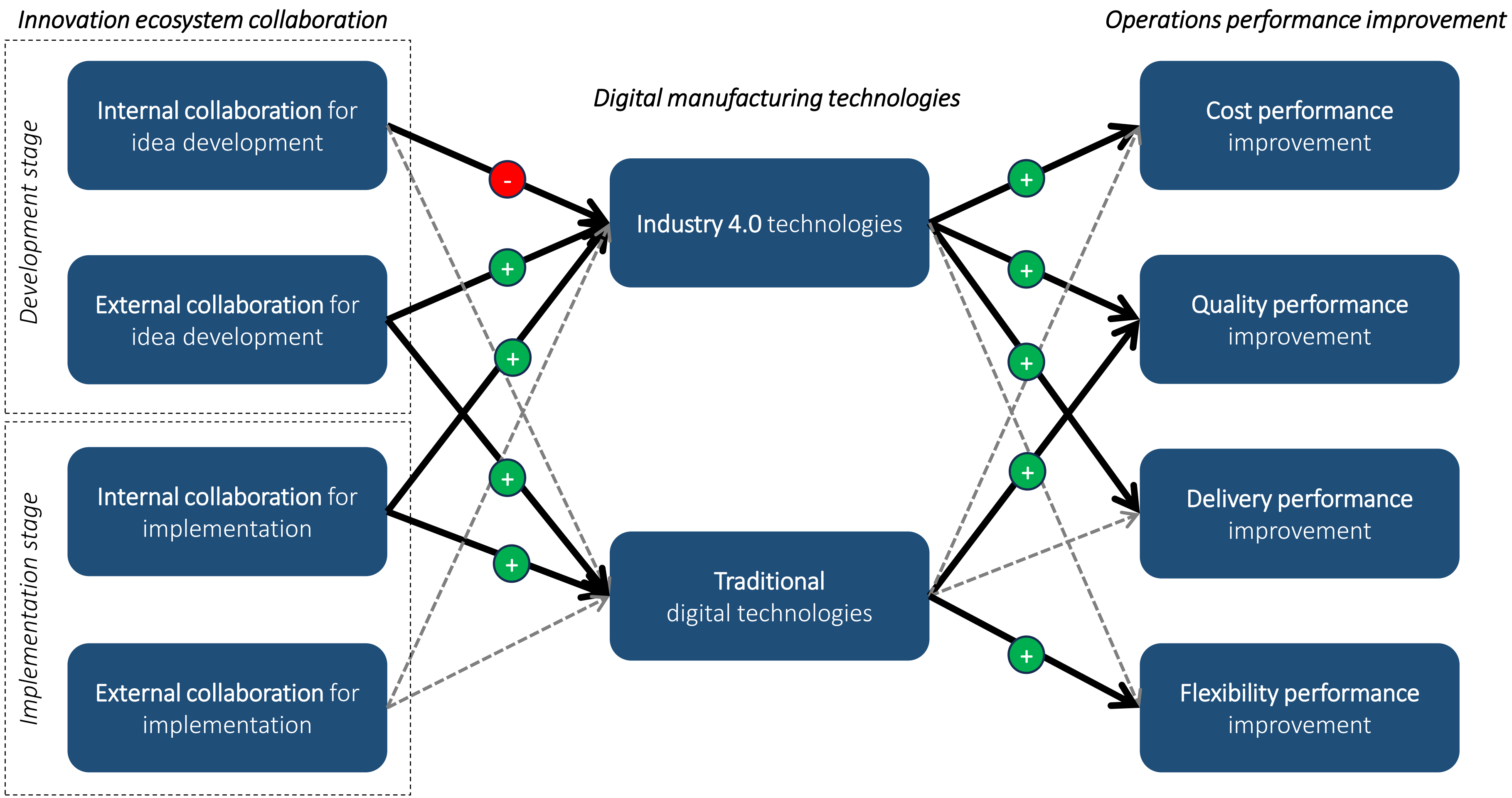
Legend: *above the threshold level* / *below the threshold level*

Source: own construction

Findings

The results provide evidence of the different role of internal and external innovation ecosystems on digital technologies (both traditional and I4.0).

Results of structural equation modelling



Source: own construction

Findings

The results provide evidence of the different role of internal and external innovation ecosystems on digital technologies (both traditional and I4.0).

Results of hypothesis testing

Relationships	Path coeff.	p-value	Hypothesis
Idea development phase			
Internal collaboration -> I4.0 technologies	-0.162	0.032	H1 rejected (inverse)
Internal collaboration -> Traditional technologies	-0.135	0.188	H2 rejected
External collaboration -> I4.0 technologies	0.485	0.001	H3 accepted
External collaboration -> Traditional technologies	0.327	0.032	H4 accepted
Implementation phase			
Internal collaboration -> I4.0 technologies	0.137	0.033	H5 accepted
Internal collaboration -> Traditional technologies	0.432	0.000	H6 accepted
External collaboration -> I4.0 technologies	0.106	0.422	H7 rejected
External collaboration -> Traditional technologies	-0.202	0.148	H8 rejected
Performance effects			
I4.0 technologies -> Cost performance	0.438	0.000	H10a accepted
I4.0 technologies -> Quality performance	0.128	0.030	H10b accepted
I4.0 technologies -> Delivery performance	0.168	0.043	H10c accepted
I4.0 technologies -> Flexibility performance	0.055	0.524	H10d rejected
Traditional technologies -> Cost performance	-0.002	0.982	H9a rejected
Traditional technologies -> Quality performance	0.467	0.000	H9b accepted
Traditional technologies -> Delivery performance	-0.207	0.132	H9c rejected
Traditional technologies -> Flexibility performance	0.199	0.021	H9d accepted

Source: own construction

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Conclusion

The paper contributes to the exploration of the impact of innovation ecosystems on the implementation of digital technologies in manufacturing and their operations performance implications.

Summary

The involvement of external innovation ecosystem actors during the development stage significantly boosts digital technology adoption *(knowledge exploration)*.

The involvement of internal innovation ecosystem actors during the implementation stage significantly boosts digital technology adoption *(knowledge exploitation)*.

There is no major difference between I3.0 and I4.0 technologies in terms of the role of the innovation ecosystem. One exception: intense internal ecosystem collaboration during the idea phase reduces I4.0 implementation *(lack of internal knowledge)*.

Somewhat stronger performance impact of I4.0 technologies *(cost, quality, delivery, but not flexibility)*, with positive implications for traditional technologies too *(quality, flexibility)*.

Source: own construction

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Thank you for your attention!

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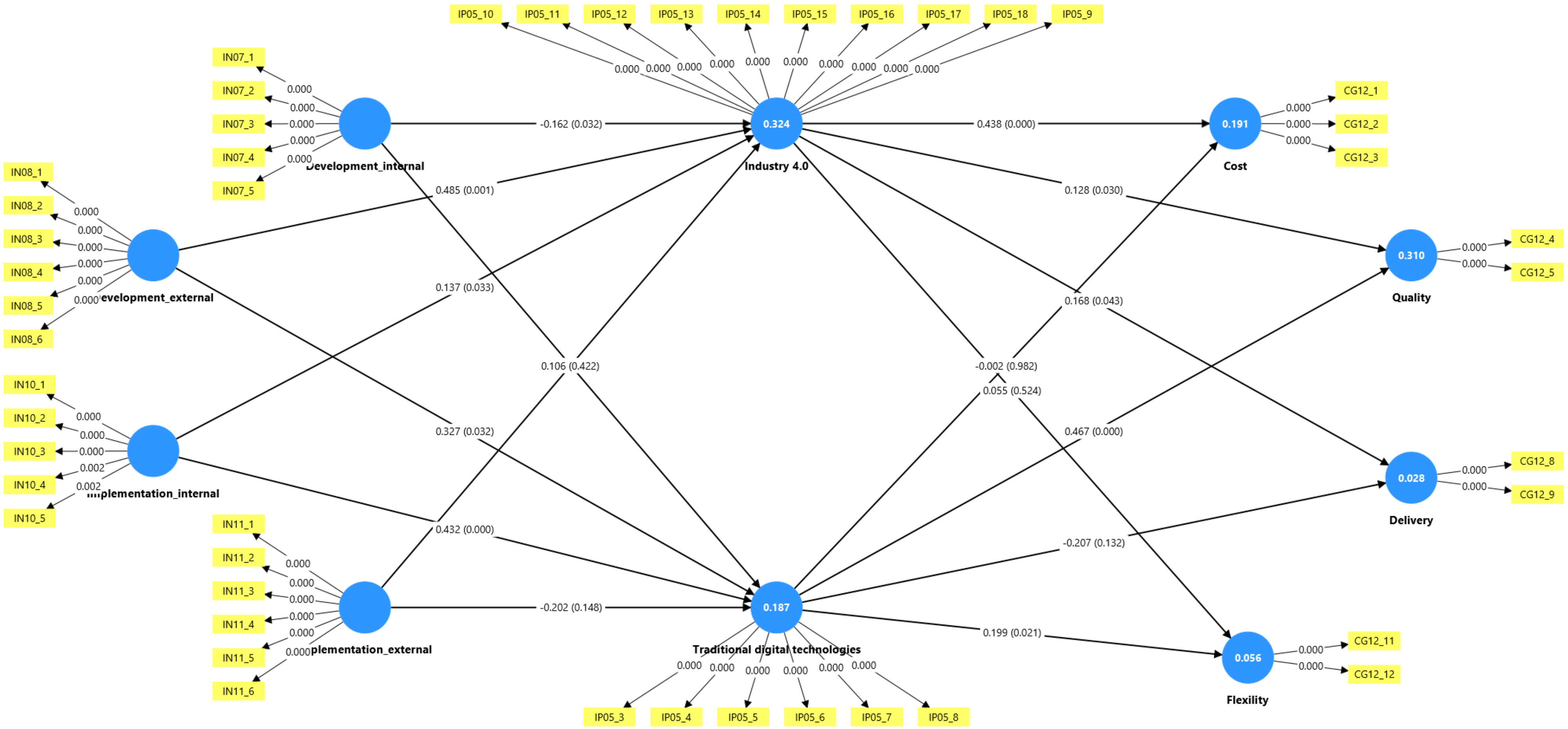
Appendix

The structural model in SmartPLS.



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