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Technology-push and market-pull strategies: The influence of the innovation ecosystem on companies' involvement in the Industry 4.0 paradigm

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Abstract

Purpose: This study analyzes how the innovation ecosystem helps integrate technology-push and market-pull strategies in the Industry 4.0 paradigm.

Methodology/approach: This study investigates companies' involvement in the Industry 4.0 paradigm through technology-push strategies, and through both technology-push and market-pull strategies. We perform two econometric logit models to test the influence of collaborations with heterogeneous actors, research and university relationships, and relations with business incubator (the pivot actor) on companies' involvement in Industry 4.0.

Main finding: The study empirically shows that developing relationships with a greater diversity of actors, collaborating with university and research laboratories, and developing intense relationships with business incubator increase the likelihood for companies to integrate both technology-push and market-pull strategies in their involvement in the Industry 4.0 paradigm

Practical implications: This study provides insights to practitioners who are interested or involved in the new Industry 4.0 paradigm. Our study explains how specific features of an innovation ecosystem, such as complex interactions among actors, can stimulate creative ideas and successfully implement innovations to address Industry 4.0 challenges.

Originality/value: First, we confirm the role of the innovation ecosystem on companies' involvement in the Industry 4.0 paradigm. Second, our study highlights that the innovation ecosystem is a new relevant framework that enables companies to integrate both technology-push and market-pull strategies. Third, we provide empirical evidence about the role of business incubator on firms' strategies to get involved in the Industry 4.0 paradigm.

Key words: Industry 4.0, Innovation Ecosystem, Technology-push strategies, Market-pull strategies, Technological paradigm

1- Introduction

The democratization of digital tools has profoundly changed society's production, consumption, and interaction habits (Alaloul *et al.*, 2020; Nuvolari, 2019). Tablets and mobile phones have taken over our daily lives. Combined with the rapid growth of mobile applications, they have opened the doors to the digital era at the service of a more agile, hyper-connected, and globalized society.

Internet has transformed people's consumption habits (Fuchs, 2007), and commerce was one of the first sectors affected by the transformation. Afterwards, the service sector evolved with the emergence of world-famous platforms, such as Uber and Airbnb (Geissinger *et al.*, 2020). With them, a new economy format was established, based on a collaborative economic model that connects service providers with costumers through a platform. In the model, the company that owns the platform only facilitates connections and does not own the products or services (Kenney and Zysman, 2016). Since new business models have changed both the economic landscape and society, traditional companies now face competition not only within the sector, but also from external players. Similarly, the finance sector was confronted by the development of disruptive digital technologies with the emergence of blockchain and cryptocurrencies (Mhlanga, 2020; Hileman and Rauchs, 2017).

Germany, which witnessed Kodak's demise due to a belated shift towards digital technologies and Google's emergence in the automotive sector, was the first to define an industrial policy focused on the digitalization of its industrial sector (Kohler and Weisz, 2016). This was the starting point for the Industry 4.0 program in 2011. Since then, other countries have launched similar programs: the United Kingdom (High Value Manufacturing Catapult), Italy (Intelligent Factory Cluster), the Netherlands (Smart Industry), Belgium (Made different in Flanders and Plan Marshall 4.0 in Wallonia), China (China Manufacturing 2025), the United States (Smart Factories & IoT), and France (*la nouvelle France industrielle*).

While most of the programs are based on science and technology perspectives, customer preferences are shifting toward lower spread or more personalized products (Patnaik, 2020). Beyond a technology-push perspective of the Industry 4.0 paradigm, more researchers are focusing on market features, including characteristics of the customers and users' behaviors that refer to a market-pull perspective as drivers of Industry 4.0 development. Kline and Rosenberg (1986) advocates a more interactive model between technology-push and market-pull as an alternative to the technology-push or demand-pull linear model. However, as innovation processes are becoming increasingly complex, a more successful framework with greater possibilities is still needed to integrate both technology-push and market-pull strategies (Di Stefano *et al.*, 2012). This need is especially important as the current fourth industrial revolution far exceeds previous industrial revolutions in terms of importance, scope, and complexity. Benitez *et al.*, (2020) show that the ecosystem-based approach is more suitable for the development of Industry 4.0 paradigm. The innovation ecosystem is a complex and dynamic system characterized by heterogeneous actors, organizations, and institutions involved in complex relationships to develop innovation process (Granstrand and Holgersson, 2020; Gomes *et al.*, 2018). The ecosystem influences firms' adaptive capacity to deal with technological, institutional, and market change (Boyer *et al.*, 2021). Thus, the ecosystem can facilitate the integration of both technology-push and market-pull strategies.

To what extent does the innovation ecosystem facilitate the integration of both technology-push and market-pull strategies in the Industry 4.0 paradigm? Until now, there is a lack of empirical and theoretical evidence that confirms the role of the innovation ecosystem on companies' involvement in the new Industry 4.0 paradigm. Furthermore, the innovation ecosystem's role on technology-push and market-pull strategies toward the development of Industry 4.0 is not yet truly addressed. This study aims to fill this gap through examining the companies involved in Industry 4.0 in the Hauts-de-France's information and communication technologies (ICT) and digital ecosystem.

The rest of the study is organized as follows: Section 2 presents the theoretical background, while Section 3 explains the methodology. Section 4 discusses the main results. Section 5 presents the main conclusions and contributions.

2- Theoretical background

2.1 Industry 4.0 definition and main technologies

Initially used in 2011 at the Hannover Fair in Germany, Industry 4.0 is defined as "the integration of complex physical machinery and devices with networked sensors and software, used to predict, control, and plan for better business and societal outcomes." (Industrial Internet Consortium, 2013, cited by Lu, 2017). It is a new technological paradigm based on cyber-physical systems, smart factories, and the Internet of things (IoT) that gather people, machines, and data within a production process of goods and services.

Several technologies are needed to build up Industry 4.0. They include IoT-based intelligent devices, such as sensors, actuators, or intelligent products that gather and process relevant data to let the machines make the decisions (Bongomin *et al.*, 2020). Cooperative robots (cobots) and autonomous mobile robots enable production to flexibly adapt and react to new requirements, achieving production of lot size one (Gorecky *et al.*, 2014). Digital twins model various processes within companies, including overall product lifecycle management, production and logistic planning, and the deployment and management of remote resources (Haag and Anderl, 2018; Tao *et al.*, 2018). Using "physical" digital twins could reduce the time to market. For example, the time to market of Gebo Cermex's product is reduced by 10-15% [1]. The use of "data driven" digital twins can further optimize product and production design during the lifetime.

Virtual and augmented reality devices are mostly used for design, maintenance, and training (Ong and Nee, 2013). To allow end-to-end communication, humans and production plants use Internet technologies and communicate directly without hierarchy. The convergence of Operational Technology and Information Technology (IT) networks allows the use of local, edge, or cloud computing. Edge computing provides intelligent services that meet key requirements of intelligent manufacturing for flexible reliable connection, real-time processing, data cleaning, and privacy protection. Cloud technologies, cybersecurity, big data, and data analytics are used for industrial supply chain analysis and optimization, product quality control, and active maintenance (Chen *et al.*, 2017). Artificial Intelligence (AI) allows companies to provide data-driven services, such as predictive maintenance for machines on the plant or products, quality control, and machine as a service (Patnaik, 2020). According to Lasi *et al.* (2014), the industry 4.0 paradigm is also supported by the market-pull and technology-push approaches.

2.2 Technologies-push or market-pull approach: Which one drives the Industry 4.0 new paradigm?

The technology-push approach is based on the linear model of innovation to create a competitive advantage and new value proposition (Di Stefano *et al.*, 2012). It refers to the process in which innovation is pushed to the market through technology development within the firm's R&D department or technology transfer from research organizations to firms. Therefore, technology-push can be based on the company's internal competences and adoption of disruptive technologies (Walsh *et al.*, 2002). Technology-push strategies aim to create relevant products and services for customers and end-users without any explicit market expression for such technologies. Technology orientation strategies depend on R&D investments, university–industry collaboration, or brokers that facilitate technology transfers between research organization and companies. Furthermore, pushing new technologies to market needs tests on the feasibility and maturity of the technologies, investments in diffusion, and strategies for the adoption of such technologies.

Industry 4.0 could be viewed through a technology-push approach (Fasi *et al.,* 2014). In France, the usual concept that refers to Industry 4.0 is "*the industrie du futur*". The "*industrie du futur*" concept[2] generally refers to the digital transformation of the industrial fabric, tools, equipment, and companies through digital technologies, such as AI, big data, and cobotics. Germans view Industry 4.0 as the use of digital technologies to produce small series of products at the same cost as mass-produced products or large-scale production (Kohler and Weisz, 2016). These Industry 4.0 approaches is supposed to integrate digital technologies into the firm's production process or into supply chain management.

Niryo[3], a start-up created in 2016 and based in Lille, France, is an example of how technology-push strategies are used to drive involvement in Industry 4.0. It aims to make robotic technology accessible to everyone in terms of skills and costs. Ned, which was launched by Niryo in 2019 for student education and life-long training, is a 6-axis collaborative robot, powered by open-source technologies (Raspberry Pi and ROS); it has several grips capabilities, a vision set, and a conveyor belt. Ned's software solution is open and easy to integrate with the other technologies typically used in universities such IoT hardware or MATLAB and Python. The company also provides tutorials for teaching purposes. In addition, the community can also propose their own tutorials in a logic of open-source creative commons. Deutsche Bahn uses Ned to train their apprentices in using a robot and integrating it to the whole production chain. Ned is chosen because of its interoperability with the IT network and the control system made by Siemens[4]. The robot can be viewed as an IoT device, which can be utilized in different industrial environments; it can easily be programmed even by people without specific skills in robotics.

On the other hand, in the market-pull approach, the impulse to develop or use new technologies comes from consumers, end-users, or other individuals or groups that express their needs (Isoherranen and Kess, 2011). According Brem and Voigt (2009), the market-pull approach involves an unsatisfied customer that creates a new demand, which requires problem solving; the goal is to satisfy customers and end-users. To do so, companies should clearly know their markets to identify valuable customer propositions. Companies should also observe the evolution of customers' preferences and push forward the use of technologies or technologies development. Day (1998) and Slater and Narver (1995) provide some characteristics of market-driven organizations: i) they focus on customer value; ii) they know their markets deeply and understand customers' needs, both expressed and latent ones; iii) they are able to convert customer satisfaction into loyalty; iv) they are proactive about market change and the evolution of customer preferences; and v) they develop innovative solutions for ensuring high customer value.

Industry 4.0 could be viewed through a market-pull approach (Fasi *et al.*, 2014). The industry 4.0 is based on the shift from a "Mass Production" perspectives (production of large amounts of standardized product) toward am "Mass customization" perspectives (production of personalized products and services or lot size one). The end-customers are main drivers for the market-pull approach, and their consumption habits are completely transformed by the Internet and digital technologies. They are more mobile and connected because of mobile devices, WiFi, and 4G. Social networks allow them to exchange their opinions in real time. They are progressively more demanding about product quality, origin and ecological footprint, child labor, and prices. Social change in the context of ecological aspects require a more intensive focus on sustainability in industrial contexts. The aim is an economic and ecological increase in efficiency. Therefore, companies must adapt to remain competitive. They must transform their production from large batches with few variants to "lot size 1" custom products, and evolve from being product- to service-oriented—also called servitization. Industry 4.0 technologies let companies interact with their customers for product customization purposes.

Plastisem, a French small and medium enterprise (SME) specializing in manufacturing injected plastic parts, has integrated a clear-market-pull strategy for business development. A fully integrated industrial player, it has retained the triple competence of 3D design, tooling manufacture, and plastic injection. In 2019, a customer was looking for a new product, which was not part of its standard products and services. To meet that new requirement, Plastisem installed its first cobot. The new technology not only enabled the company to provide complementary service to all customers, but it also enabled the integration of the new technology into the company's existing production process.

This study assumes that integrating both technology-push and market-pull strategies is the best approach to address Industry 4.0 issues and to get efficiently involved in this new paradigm. For greater efficiency, Industry 4.0 is supposed to integrate digital technologies into the production process or supply chain management. However, it requires exploiting users' data to capture need and preference evolutions, while remaining proactive. The best example of combining both technology-push and market-pull strategies is product personalization and the co-design of products with customers or end-users. Integrating digital technologies, such as AI, IoT, big data, and cloud computing, into the industrial process allows firms to offer services and products to customers or end-users promptly and at low costs because of personalized and flexible production processes (Weking *et al.*, 2020). In this perspective, Industry 4.0 requires developing co-evolution between technologies and market needs or end-users' preferences.

Exotec, a French SME created in 2014 and based in Northern France, uses a pull-push business strategy. Besides operator workstations, it offers a complete supply chain robotic solution: racks, bins, autonomous robots, and an articulated arm able to move solid objects. It offers an extremely flexible solution that adapts to the architecture of the customer warehouse to allow optimizing the full available volume. Sizing is based on both floor space and ceiling height, with robots designed to climb on the racks. Storage space can rise up to 12 meters high, increasing density fivefold compared to traditional shelf picking. The storage system is designed to adapt quickly and easily to customers' needs and business growth. Exotec's business development strategy includes looking for long-term partnership to support the customers' own need to innovate. Decathlon, a large French company, works closely with Exotec for its European logistic operations. Decathlon's technology, based on autonomous collaborative mobile robots, AI, and system integration, enables Exotec to help its customers improve their productivity and offer workers better work quality.

Integrating both technology-push and market-pull approach into an overall innovation strategy requires relevant frameworks and tools that could incorporate both dynamic technologies and users' and consumers' preference evolution.

2.3 Innovation Ecosystem: a new framework toward integration of technology-push and market-pull strategies

An innovation ecosystem is a complex network of heterogeneous actors developing interdependent interactions (formal and/or informal) and co-evolving in a strategic context to develop innovation processes and new paths for value creation (Moore, 1993; Adner, 2006; Russell and Smorodinskaya, 2018). This approach goes beyond strategic relations of complementarity around a focal firm (Business Ecosystem) to encompass more complex and dynamic relations between a set of actors having different attributions, interests, behaviors, and responsibilities (Cohendet *et al.*, 2020). The innovation ecosystem is also a complex adaptive system that adapts its components continuously in order to respond to change, environment dynamics, and internal disturbances (Gunderson and Holling, 2001). Benitez *et al.* (2020) show that the ecosystem-based approach is more suitable for the Industry 4.0 paradigm, which requires a "complex system of interconnected digital technologies, information systems and processing technologies that demand high competences interdependency and technological complementarity" (Dalenogare *et al.*, 2018; Reischauer, 2018).

The ecosystem dynamic relies on co-evolution (Moore, 1996; Hou and Shi, 2021), which considers firms, research and development organizations, institutions, artefacts, technologies, and end-users—including their behaviors and preferences (Granstrand and Holgersson, 2020; Hou and Shi, 2021). The innovation ecosystem enables actors to adjust their behavior and strategies in dealing with market and technological changes (Russell and Smorodinskaya, 2018). By addressing both technological and market issues through a systemic perspective, the ecosystem appears to be a relevant framework to drive technology-push and market-pull strategies. Moore (2006) notes that ecosystems expedite coordination of innovation in goods and the activities that produce them, and facilitate managed co-evolution of the complex web of markets and hierarchies themselves.

Existing studies on platform-based ecosystem identify digital platform as the key driver that fosters co-evolution between actors, technologies, and end-user preferences (Gawer and Cusumano, 2014; Hein *et al.*, 2020; Tiwana, 2013). The digital platform provides a breeding ground for ongoing interactions between the platform's owner, application developers, and end-users. A digital platform is an extensible, adaptable, and multivalent software product or service with the ability to customize its capabilities. It serves as a foundation on which others can build complementary products or services that interoperate through the platform's interfaces (Tiwana, 2013).

Similarly, recent studies on local and regional innovation ecosystem highlight the role of the middleground as an alternative platform that promotes co-evolution within the ecosystem and firms' adaptive capacity toward technological and market change (Cohendet *et al.*, 2020; Boyer *et al.*, 2021). By connecting the actors with greater explorative capacity (underground) and actors with greater exploitative capacity (upperground), the middleground allows actors to incorporate new market trends and new technological perspectives. The ecosystem could enable actors to develop both technology-push and market-pull strategies to address technological and market change.

Existing literature on platform and local innovation ecosystems presents theoretical evidence that innovation ecosystem could enable actors to integrate both technology-push and market-pull strategies as drivers toward involvement into the new Industry 4.0 paradigm (Tiwana, 2013; Cohendet *et al.*, 2020; Fasi *et al.*, 2014). The ecosystem is crucial for the production and adoption of technologies by providing organizational and technological conditions for firms and end-users (Benitez *et al.*, 2020; Venkatesh *et al.*, 2007). However, empirical analysis is needed to test the extent to which the innovation ecosystem facilitates the integration of both technology-push and market-pull strategies in the Industry 4.0 paradigm.

3- Methodology

3.1 The ICT and digital innovation ecosystem in Hauts-de-France

The ICT and digital ecosystem in Hauts-de-France is a young and teeming ecosystem, which upholds strong and complex relationships between heterogeneous stakeholders, including companies, research laboratories, technological structures, finance organization, brokers, and start-ups (Boyer *et al.*, 2021, Liffoogue *et al.*, 2016). This ecosystem is part of Hauts-de-France's transformation process, which involves converting the region's productive makeup, from steel and textile industries toward new industrial specializations (Paris and Stevens, 2000; Liefooghe *et al.*, 2016). This ecosystem is created around a pivot actor, Euratechnologies. Euratechnologies is a business incubator and accelerator, which hosts around 300 ICT and digital sector companies.

Using data from a regional database, Boyer *et al*., (2021) employs entropy analysis (Modified Herfindahl Index) and confirms that this ecosystem brings together firms with high sectoral diversity into a strategic and collaborative context. Beyond firms' sectoral diversity, the Hauts-de-France's ICT and digital ecosystem gathers start-ups, SMEs, and subsidiaries of large companies, such as IBM and Microsoft. Furthermore, several organizations with different roles, attributes, goals, and perspectives are part of this ecosystem.

Some actors that are part of the ecosystem are as follows: The National Institute for Research in Digital Sciences and Technologies (INRIA-Lille) is the main research center that feeds this ecosystem, besides the University of Lille and the Catholic University of Lille. The competitiveness poles agency *Picom by cap digital*, which specializes in e-commerce and facilitates the development of R&D collaborative project between actors, is involved in the animation of a more than 125-actor network. The CITC, which runs the IoT cluster with more than 50 companies, is also a major actor in this ecosystem. Finally, we highlight the presence of openlabs and fablab, such as Techshop Lille, and makers and geek communities such as the *Catalyst*, *Anis,* and *Roumics* communities (Boyer *et al*., 2021).

The Hauts-de-France digital and ICT ecosystem promotes diversified relationships that are relevant for the Industry 4.0 development. Boyer *et al.* (2021) identifies complementary relationships through collaborative R&D projects; relationships between large groups, research centers, business angels and start-ups; informational and communicational relations; learning relationships; and informal relationships, mainly throughout tech and digital events.

Moreover, since the ICT and digital innovation ecosystem in Hauts-de-France includes actors that favor innovation driven by science and technologies (i.e., technology-push strategies) (INRIA research center, Universities), and actors who promote market-pull strategies for the innovation process, this ecosystem can be used to study the development of Industry 4.0 technologies through technology-push and market-pull perspectives.

3.2 Research design

This study generally analyzes the role of the innovation ecosystem on companies' involvement in the Industry 4.0 paradigm. Specifically, it aims to describe the main Industry 4.0 technologies exploited by companies located in Hauts-de-France; and test the influence of relationships built with heterogeneous actors, science-industry relationships, and relationships with the business incubator, the pivot actors (keystone), on company's involvement in Industry 4.0 either through technology-push strategies or both technology-push and market-pull strategies.

We use descriptive analysis to examine the Industry 4.0 technologies exploited by companies. We also use multiple correspondence analysis to identify correspondences between several technologies exploited by companies and detect possible technology clusters. These potential groups are then validated by Chi-square tests.

In addition, we construct two econometric models to test the influence of collaborations with heterogeneous actors, research and university relations, and business incubator (the keystone actor) on company's involvement in Industry 4.0 either through technology-push strategies or both technology-push and market-pull strategies.

Several studies show the crucial role of developing relationships with heterogeneous actors in innovation processes (Corsaro *et al.*, 2012). Moreover, an ecosystem is defined as a set of heterogeneous actors involved in complex relationships within a strategic environment (Adner, 2006; Autio, 2021, Adner, 2017; Gomes *et al.*, 2018). However, further research is needed to determine the extent to which the heterogeneous actors' influence the companies' involvement in the Industry 4.0 paradigm.

Some studies emphasize that universities are critical in terms of knowledge production and diffusion within the ecosystem (Heaton *et al*., 2019; Carayannis and Campbell, 2009). Universities are also involved in developing human capital and advancing technology. Furthermore, besides teaching and research activities, universities can actively stimulate growth by engaging with partners in local economies to launch new industries, fostering entrepreneurship, and revitalizing neighborhoods (Compagnucci and Spigarelli, 2020). Existing studies on Triple Helix indicate the role of interactions of academia, industry, and government in innovation processes and regional or national competitiveness (Etzkowitz and Leydesdorff, 2000). Kohler and Weisz (2016) note that the Industry 4.0 concept came from a Triple Helix program in Germany, which gathered academia, industry, and government actors. Carayannis and Campbell (2009) indicate that the innovation ecosystem could be viewed as a Quadruple Helix perspective, emphasizing the importance of the media-based and culture-based public in addition to academia, industry, and government interactions. Heaton *et al*. (2019) state that universities and their interactions with local actors are part of a capabilities-based life-cycle of innovation ecosystem and are essential in the ecosystem's renewal. These considerations justify the importance to test the role of university-industry relations on firms' involvement in a new technological paradigm such as Industry 4.0.

A major proposition from the ecosystem literature is the role of the pivot actor or keystone. This concept is an analogy of the ecological concept of keystone species, which are species whose activities determine "the integrity of the community and its unaltered persistence through time, that is, stability" (Paine, 1969; Bond, 1994). Iansiti and Levien (2005) identify the keystone firm or organization as the anchor that ensures growth and stability in the ecosystem. Therefore, exploring the presence of a keystone and how it affects firms' dynamics becomes important in the analysis of the ecosystem. In our study, it is the business incubator, Euratechnologies that plays the role of the Keystone actor in the ICT and digital ecosystem of the Hauts-de-France region.

3.3 Data source

This study used data from the regional database *Astride*. The *Astride* database provides a wide range of data on more than 200,000 companies and organizations in Hauts-de-France since the 2000s. It provides information on the economic, technological, and structural characteristics of companies and organizations, as well as public policies and support. Using the database, we identified 372 companies officially involved in the development of Industry 4.0 in Hauts-de-France.

We also used the results of an original survey on 123 companies already involved in Industry 4.0. The survey was carried out in 2018 and 2019. This sample represents 33% of companies officially identified in *Astride* as companies that are already involved in Industry 4.0. This survey provided data on the Industry 4.0 technologies commonly exploited by companies, the context of the development or appropriation of Industry 4.0 technologies, and collaborations and relationships that companies develop with heterogeneous actors in the regional innovation ecosystem. Additionally, the survey also analyzed whether the companies' involvement in the Industry 4.0 paradigm were through technology-push strategies, market-pull strategies, or both technology-push and market-pull strategies.

3.4 Econometric models

3.4.1. Model specification

We perform two logit models in this study. The first model aims to test the influence of relationships with heterogeneous actors, the pivot actor (the business incubator Euratechnologies), and universities or research laboratories on the company's involvement in Industry 4.0 based on both technology-push and market-pull strategies.

The first logit model refers to the likelihood that the company's involvement into Industry 4.0 is through both technology-push and market-pull strategies. It is written as

$$L_i = ln(\frac{P_i}{1 - P_i}) = \alpha + \beta' X_i \qquad (1)$$

Where:

L_i is the log odds ratio of the probability that the company's involvement into industry 4.0 is based on both technology-push and market-pull strategies;

P_i is the probability that Z_i =1, if the company's involvement into Industry 4.0 is based on both technology-push and market-pull strategies.

$1 - P_i$ is the probability that Z_i = 0, the company's involvement in Industry 4.0 is not based on both technology-push and market-pull strategies.

β_i= the coefficients of the explanatory variables to be estimated. The unknown parameters βi are usually estimated by the maximum likelihood procedure

Z_i is defined as a dummy variable that takes the value of 1 if the company's involvement in Industry 4.0 is based on both technology-push and market-pull strategies, and 0 otherwise.

X_i is defined as the independent variables.

The second model aims to test the influence of relationships with heterogeneous actors, the pivot actor, and science-industry on the company's involvement in Industry 4.0 based only on technology-push strategies. The second logit model is written as

$$K_i = ln\left(\frac{P_i}{1 - P_i}\right) = \alpha + \beta' X_i \qquad (2)$$

Where :

K_i is the log odds ratio of the probability that the company's involvement in Industry 4.0 is based only on technology-push strategies.

P_i= is the probability that Y_i =1, if the company's involvement in Industry 4.0 is only through technology-push strategies.

$1 - P_i$ is the probability that Y_i =0, if the company's involvement in Industry 4.0 is not based only upon technology-push strategies.

Y_i is defined as a dummy variable that takes the value of 1 if the company's involvement in Industry 4.0 is only through technology-push strategies, and 0 otherwise.

X_i is defined as the independent variables.

This study does not include a third model about market-pull only strategies because it failed to robustness test. We prefer to focus on the comparison between technology-push and push-pull strategies.

It is also important to specify that α , β' and X_i are not the same in the two equations, because we have two distinct logit models.

3.4.2. Independent variables: measures and justification

Our study aims to test the role of relationships between heterogeneous actors, the business incubator as the pivot actor, and university and research laboratories within the innovation ecosystem on companies' involvement in Industry 4.0, whether they are based only upon technology-push strategies or both technology-push and market-pull strategies.

We first use the count variable *Het_actors,* which refers to the diverse actors the company develops relationships with in the ecosystem (e.g. universities, private R&D organizations, companies, openlabs, public organizations, and business incubators). Next, we use the variable *UI_links,* which refers to direct university-industry or science-industry relationships that a given company generally develops in its innovation process (Giuliani, 2009).

Afterwards, we use a proxy based on a proposition from the ecosystem literature that highlights the role of the pivot actor or keystone. We use the count variable *keyst,* which refers to the intensity of relationships a given actor develops with the keystone. In our case, the keystone is Euratechnologies. *Keyst* expresses the different forms of relationships that a given company develops with the pivot actor of the ecosystem. These interactions include complementary relationships through innovative projects, customer-supplier relationships, learning relationship (seminar, professional training, and workshop), formal networks, informational and communicational relationships (information sharing, competitive intelligence, technology watch), and informal relationships (ad hoc mutual support, ad hoc and informal advice, and participation in events or in an epistemic community).

Lastly, we use four control variables. We use the *Age* and *Size_comp* variables, which refer to the company's age and size, respectively. Variable *Size_comp* is a scale variable from 1 to 4 (Oliveira *et al*., 2014). We adopt then, the National Institute of Statistics and Economic Studies (INSEE) classification (micro, small, medium, or large companies). In addition, *w*e use the *Tech_4* count variable, which refers to the number of Industry 4.0 technologies a firm exploits in its production process. The fourth variable is *Aid_Region.* Used by the Hauts-de-France regional Innovation Agency, *Aid_Region* represents the importance of public support provided to companies engaging in innovative activities.

Tables 1 and 2 summarize all variables in in our study.

Table 1. Summary statistics (frequencies and percentages)

Variables	Description	Categories	freq	percent
Push_Pull	Dummy variable, which takes the value 1 if company's involvement in industry 4.0 is based upon both technology push and market pull strategies	Push_Pull=1	39	32%
		Push_Pull=0	84	68%
Push_only	Dummy variable, which takes the value 1 if company's involvement in industry 4.0 is based upon only a technology push strategies	Push_only=1	42	34%
		Push_only=0	81	66%
UI_links	Dummy variable which takes value 1 if the company is used to collaborating with research centres and universities and 0 otherwise	UI_links=1	71	58%
		UI_links=0	52	42%
Size_comp	Scale variable, which expresses the Size of the firms using categories of INSEE based on the number of employees	Micro companies (X< 10 employees)	47	38%
		Small companies (10 ≤ X<250 employees)	46	37%
		Medium companies (250 ≤ X<3000 employees)	12	10%
		Large companies (X ≥ 3000 employees)	18	15%
Aid_region	Scale variable from 0 to 5, which expresses the level of regional support received by a given company for innovative activities.	No regional support	36	29%
		Very weak regional support	29	24%
		Weak regional support	9	7%
		Moderate regional support	7	6%
		Strong regional support	24	19%
		Verry strong regional support	18	15%

Table 2. Summary statistics (means and standard deviation)

Variables	Mean	Std. Dev.	Min	Max
Aid_region	2.065041	1.893647	0	5
Nb_tech	3.373984	2.189387	1	11
Size_comp	2.00813	1.036197	1	4
age_comp	27.90244	37.36449	1	196
Keyst	1.455285	2.108733	0	6
Het_actors	3.170732	2.310728	0	8

4- Mains results and discussions

4.1 Technologies of Industry 4.0 exploited by companies

Table 3 shows the main Industry 4.0 technologies exploited by companies in Hauts-de-France. Cloud computing is the most exploited technology, as 66% of the companies utilized it. Big data, machine learning, and cyber security follows at 45%, 44%, and 43%, respectively. IoT is exploited by 31% of companies. Deep learning, digital twin, cobot, and augmented reality or virtual reality (AR/VR) are utilized by at least 20% of the companies. Lastly, 3D printing, RFID, and Blockchain are used by less than 10% of companies.

Table 3. Main Industry 4.0 technologies exploited by companies in the Hauts-de-France region

Techno	**freq**	**perc**
Cloud Computing	81	66%
Bigdata	55	45%
IA_Machine Learning	54	44%
Cyber Security	53	43%
Internet of Things	38	31%
IA_Deep Learning	29	24%
Digital Twin	26	21%
Cobot	25	20%
ARVR	24	20%
3D printing	10	8%
RFID	8	7%
Blockchain	6	5%
AGV	5	4%

Fig. 1 and Table IV show that the ACM allows us to spatialize the results and identify four technology clusters exploited by companies, as well as possible Industry 4.0 technological pathways in Hauts-de-France.

Cluster 1 brings together hosting and securing data technologies, such as cloud computing, cyber-security, and big data. It is a consistent result because cloud solutions are generally used to house large amounts of data and require secure infrastructures (Wang *et al.*, 2016). Cluster 2 groups technologies related to the exploitation of massive data through AI, including deep learning and machine learning. The technologies are based on the utilization of big data and on autonomous learning techniques linked to neural networks (LeCun, Bengio and Hinton, 2015). Therefore, AI development requires a large amount of data.

Cluster 3 involves human-machine interaction technologies, such as the cobots, AGV (autonomous vehicle), and AR/VR. In fact, AR/ VR could support machine learning to expand robots' abilities and help robots learn complex tasks (Gorecky *et al.*, 2014). Cluster 4 includes technologies for the operationalization of IoT, including IoT sensors, digital twin, and RFID. IoT operationalization requires technologies for identification, collection, storage, and remote data transmission such as RFID (Madakam *et al.*, 2015). It also requires using digital representations or virtual replicas of a physical object or system (digital twins) to optimize IoT deployment for maximum efficiency and continuous improvements (Hofmann and Branding, 2019).

Figure 1. Main cluster of industry 4.0 technologies exploited by companies in Haut-de-France

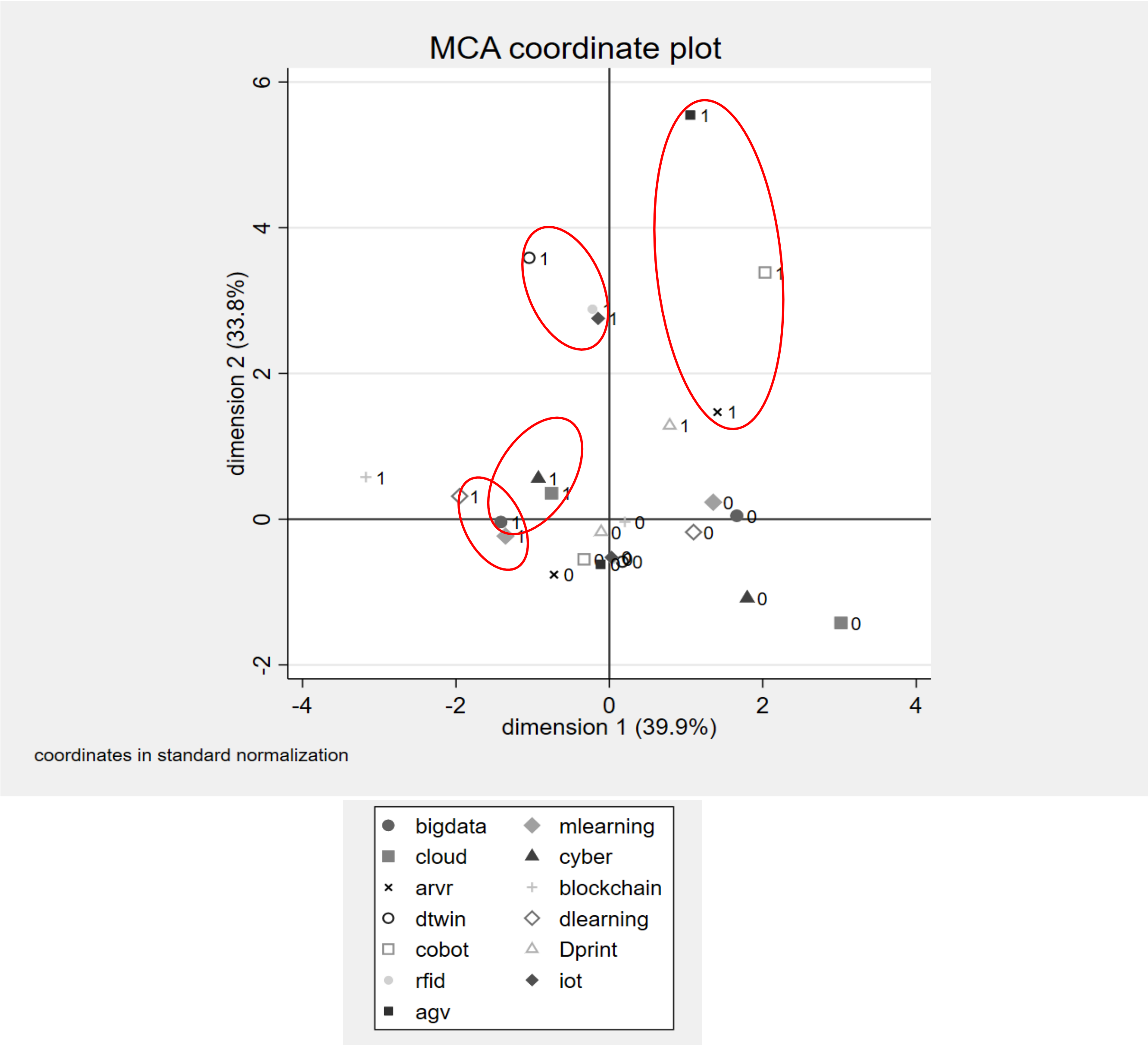

Table 4. Correlation (Chi2 Pearson) among industry 4.0 technologies clusters

Clusters	Technologies	Pearson chi2
Cluster 1	Cloud-Computing/Cybersecurity	11.7870 ***
	Bigdata/Cybersecurity	3.6284*
	CloudComputing/Bigdata	5.8172**
Cluster 2	Bigdata/Mlearning	9.7424***
	Mlearning/Dlearning	8.6806***
	Deep Learning	6.4015**
Cluster 3	Cobot/ AGV	9.7638 ***
	Cobot/ARVR	5.0814**
	AGV/ARVR	5.2387 **
Cluster 4	Iot_Sensors/ Digital Twin	4.3684**
	Iot_Sensors/ RFID	3.2756*
	RFID/ Digital Twin	0.0178

*Significant at 0.1 level; **significant at 0.05 level; ***significant at 0.001 level.

4.2 Technology-push and demand-pull strategies toward Industry 4.0 technological development: The role of the ecosystem

Table 5 shows that the number of companies involved in the Industry 4.0 paradigm through technology-push and market-pull strategies are almost the same. This results confirm the coexistence of these two perspectives, which drive innovation processes (Di Stefano *et al.*, 2012; Walsh *et al.*, 2002). This duality is the driving force for the Industry 4.0 paradigm (Fasi *et al.*, 2014). However, 32% of the companies are involved in the Industry 4.0 paradigm through both technology-push and market-pull strategies.

Table 5. Sample of companies exploiting industry 4.0 technologies and type of strategies

Strategies of companies involved into the industry 4.0 paradigm	**Nb**	**percentage**	**Strategies of companies involved into the industry 4.0 paradigm**	**Nb**	**percentage**
Companies whose involvement in the industry 4.0 paradigm is based upon a technology push strategies	81	66%	Companies whose involvement in the industry 4.0 paradigm is based upon market-pull strategies only	42	34%
Companies whose involvement in the industry 4.0 paradigm is based upon a market pull strategies	80	65%	Companies whose involvement in the industry 4.0 paradigm is based upon technology-push strategies only	42	34%
Companies whose involvement in the industry 4.0 paradigm is based upon both technology-push and market-pull strategies	39	32%	Companies whose involvement in the industry 4.0 paradigm is based upon both technology-push and market-pull strategies	39	32%
Total of companies interviewed	**123**	**100%**	**Total of companies interviewed**	**123**	**100%**

Regarding relationships developed with the actors, 90% of the companies develop relationships with the ecosystem actors. On the other hand, 58% of companies develop relationships with universities and research organizations in the ecosystem. Only 44% of companies confirm that they develop direct relationships with the pivot actor, Euratechnologies.

Table 6 highlights several points from our econometric models. Model 1*a* shows that the more a company develops relationships with more actors in the ecosystem, the higher the probability of integrating both technology-push and market-pull strategies in the Industry 4.0 paradigm. However, Model 2*a* shows that having relationships with a greater diversity of actors in the ecosystem does not influence a company's involvement in Industry 4.0 when only technology-push strategies are utilized. The results confirm that developing relationships with heterogeneous actors within an innovation ecosystem enables actors to integrate both technology-push and market-pull strategies in the Industry 4.0 paradigm. The results also empirically show how an ecosystem could affect involvement of firms in the Industry 4.0 paradigm.

Surprisingly, model 2*b* shows that university and science-industry collaboration does not influence a company's involvement in Industry 4.0 when only technology-push strategies are used. However, model 1*b* shows that university and science-industry collaborations positively affect company's involvement in Industry 4.0 when both technology-push and market-pull strategies are used. This result indicates a decorrelation between university and science-industry collaborations and the linear model of innovation. Nowadays, university and science-industry relations exceed the simple process of technology transfer or valorization of research results from university and research centers to companies. University-industry collaborations are becoming increasingly complex and bidirectional, particularly within an innovation ecosystem (Schaeffer *et al.*, 2021). These forms of collaborations could start from a market problem or end-users' needs. In our case, the competitiveness pole fosters relationships between companies and research centers or universities to address technological issues, as well as market needs.

Model 1*c* confirms that the more intense or diversified relationships with the business incubator, which is the keystone actor, are, the more likely it is that company involvement in Industry 4.0 is through both technology-push and market-pull strategies. However, model 2*c* shows that more diversified relationships with the business incubator decreases the likelihood (significant at 0.1 level) of using only technology-push strategies in the Industry 4.0 paradigm. These results show that the keystone actor could be essential in the involvement of companies in the Industry 4.0 paradigm, depending on the actor's specificities and dynamic (Boyer, 2020; Dedehayir and Seppänen, 2015). Our study shows that developing strong relations with the business incubator which is the keystone actor within the ICT innovation ecosystem in Hauts-de-France enable actors to integrate both technology-push and market-pull strategies as drivers toward involvement in the Industry 4.0 paradigm.

Using econometric analyses, this study is one of the first studies that provide empirical evidence about the role of the pivot actor (keystone) on firms' strategies in an innovation ecosystem. However, the keystone specificities are important not only in natural ecosystem, but also in an innovation ecosystem (Paine 1969; Bond, 1994; Iansiti and Levien, 2005). In our case, Euratechnologies is an innovation hub, and a business incubator and accelerator. It promotes relations between large groups and start-ups, research centers and start-ups, or business angels and start-ups. It supports firms' strategies based on technology transfers or market trends and opportunities.

In general, models 1a, 1b, and 1c show that exploiting a greater number of Industry 4.0 technologies increases the likelihood of a company's involvement in Industry 4.0 when both technology-push and market-pull strategies are employed. However, it decreases the likelihood of a company's involvement in Industry 4.0 when only technology-push strategies are utilized. The results indicate that considering market needs and their evolution may require the use of several technologies to provide relevant solutions.

Finally, models 2a, 2b, and 2c show that the higher the regional support for a given firm is, the greater the likelihood for the firm to use technology-push strategies to drive involvement in the Industry 4.0 paradigm. In contrast, the higher the regional support for a given firm is, the smaller the likelihood for the firm to use both technology-push and market-pull strategies as drivers of involvement in the Industry 4.0 paradigm. These results confirm the role of public support in innovation processes, which is more likely to help technological development. Market driven strategies are more likely a matter of firms' strategies.

Table 6. Results of logistic models

	Push-pull strategies			Technology-push strategies		
	Model 1a	Model 1b	Model 1c	Model 2a	Model 2b	Model 2c
Size_comp	0.9442 (0.2796)	0.7998 (0.2315)	1.0773 (0.3318)	1.3831 (0.3941)	1.4643 (0.4095)	1.1622 (0.3524)
Age_comp	0.9911 (0.008)	0.9914 (0.0081)	0.9915 (0.0080)	1.0050 (0.0065)	1.0055 (0.4095)	1.0044 (0.0065)
Aid_region	0.6693*** (0.1015)	0.7312** (0.0993)	0.6423*** (0.1026)	1.3801** (0.1896)	1.3021** (0.1614)	1.5067*** (0.2250)
Nb_tech	1.4558*** (0.1950)	1.4898*** (0.1983)	1.4273*** (0.1897)	0.7737** (0.1007)	0.7572** (0.0981)	0.7955* (0.1045)
Het_actors	1.2713** (0.1444)			0.8974 (0.0949)		
UI-links		2.7972** (1.2732)			1.2008 (0.4929)	
Keyst			1.3474** (0.1934)			0.7589* (0.1075)
_cons	0.1819*** (0.1168)	0.2203** (0.1291)	0.2201** (0.1303)	0.3814 (0.2238)	0.2625** (0.1433)	0.4340 (0.2387)
Pseudo R2	0.1240	0.1283	0.1232	0.0622	0.0667	0.0810
Number of obs	123	123	123	123	123	

Notes: Standard errors are shown in parentheses.
*Significant at 0.1 level; **significant at 0.05 level; ***significant at 0.01 level
An above 1 odds ratio means that there is a greater likelihood of getting the outcome; and an Odds ratio of below 1 means that there is a lesser likelihood of getting the outcome.

5- Conclusions

This study highlights the importance of the innovation ecosystem on firms' strategies to get involved in the Industry 4.0 paradigm. This study focuses on companies' involvement in the Industry 4.0 paradigm through technology-push strategies and through both technology-push and market-pull strategies. We empirically show that developing relationships with heterogeneous actors within an innovation ecosystem increases the likelihood for a company to integrate both technology-push and market-pull strategies. Moreover, university and science-industry collaboration increases the likelihood for a company to integrate both technology-push and market-pull strategies. Finally, developing intense relationships with business incubator as the pivot actor of the ecosystem also increases the likelihood for a company to integrate both technology-push and market-pull strategies.

By empirically showing the role of relationships with heterogeneous actors, university and research laboratories, and business incubator as the pivot actor of the ecosystem in influencing companies' involvement in Industry 4.0, our study provides three main contributions.

First, our study highlights that the innovation ecosystem is a new relevant framework that enables companies to integrate both technology-push and market-pull strategies. Second, we confirm the role of the innovation ecosystem on companies' involvement in the Industry 4.0 paradigm. Our study provides empirical evidence showing that complex relationships with heterogeneous actors within an ecosystem, specifically universities or research laboratories and business incubator, increase the likelihood that a company would integrate both technology-push and market-pull strategies. Third, our study exceeds theoretical considerations by providing empirical evidence, through econometric analysis, about the business incubator's role on firms' strategies to get involved in Industry 4.0.

However, further research is needed to confirm how the ecosystem approach addresses industry 4.0 issues. Further research is also needed to validate how the ecosystem approach enhances firms' capabilities to get involved in this new paradigm and to integrate both technology-push and market-pull strategies into their innovation process. This study helps practitioners, including policy makers, companies, or other stakeholders, who are interested or are involved in the Industry 4.0 paradigm. This study helps companies understand how specific features of an innovation ecosystem and complex interactions among actors could be pivotal for stimulating creative ideas and successfully implementing innovations to address Industry 4.0 challenges.

Notes:

[1] http://www.industrie-dufutur.org/Vitrines

[2] https://www.entreprises.gouv.fr/fr/industrie/politique-industrielle/l-industrie-du-futur

[3] https://niryo.com/product/ned

[4] https://www.generationrobots.com/blog/fr/preparer-les-apprentis-techniques-de-la-deutsche-bahn-a-lavenir-avec-niryo/

[5] https://www.plastisem.fr/post/mise-en-place-d-un-robot-collaboratif-6-axes.html

[6] https://www.exotec.com/en/skypod-system/

[7] Competitiveness poles are French organizational arrangements, which officially aims to develop – within a given geographic area – a competitive cluster on a given innovation and technology domain with a diversity of actors that interact mainly through R&D collaborative projects (Retour 2008)

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