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Technological drivers of seaports' business model innovation: An exploratory case study on the port of Barcelona

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ABSTRACT

The role of seaports has evolved from being simple sea/land interfaces to becoming increasingly value-adding entities in global supply chains. A port that is today at the forefront of this trend is characterized as a fifth generation (5G) port, a "smart port" or, more recently, a Port 4.0. These characterisations, introduced by Maritime Studies literature, are closely equivalent to the business model concept developed by the Strategic Management literature in the last decades. This research paper inquires on the influence that Industry 4.0 technologies might have on the adoption of more sophisticated business models by seaports, and the mechanisms through which this influence is driven: in particular the role that technology push and market pull mechanisms might play. To this end, it develops a conceptual model that aims to provide an explanation of the relationship between the adoption of Industry 4.0 technologies and the evolution of seaports' business models. This model is then evaluated against an exploratory case study on the port of Barcelona. Finally, the paper explores what would "smartness" mean in a seaport context.

1. Introduction

More than a quarter of a century has passed since the United Nations Conference for Trade and Development (UNCTAD) classified seaports into a generation scale, which at that time reached up to the third generation (3G) (UNCTAD, 1994). The extent and pace of technological evolution that has taken place until today has added two new generations (4G and 5G) to this scale, a phenomenon that has taken place in parallel with a substantial increase in the volume of international trade and, most particularly, containerized shipping (Rodrigue & Notteboom, 2015). At the same time, as a result of decreases in transportation and ICT costs, and the positioning of Asian countries —with their abundant supply of cheap labour— as manufacturing centres, value chains have become globalized and sophisticated networks (Gereffi, 2018). At the centre of those networks, as one of their core nodes, have stood seaports (Zuidwijk, 2018).

As Asia —especially China— became the "World's Factory" (Zhang, 2006), containerized shipping concentrated there, and the size of their seaports increased.[1] When analysing the role of seaports in global supply chains, maritime research and policy discussions focused on characteristics as structural connectivity (Lam & Yap, 2011; UNCTAD, 1999), emphasising aspects like port-hinterland relations (Notteboom & Rodrigue, 2008) or their suitability for being transhipment hubs (McCalla, 2008).

The prominence of infrastructure resources, geographic location, and shipping volumes as key factors for assessing a seaport's generation level has, however, given way to an increasing focus on technological capabilities; particularly those related with the Industry 4.0 paradigm. Instead of *structural* connectivity, concepts like *strategic* connectivity —associated with knowledge-intensive interorganizational exchanges between ports—, have been proposed (Hollen, 2015). Adoption of technologies like the internet of things (IoT) or blockchain, are nowadays among the main factors in evaluating a port's level of development (ESCAP, 2021; Jahn & Saxe, 2017). 5G ports have now become Ports 4.0 (Acciaro, Renken, & Dirzka, 2020; Jahn, Brümmerstedt, Fiedler, & Renken, 2018).

This increased focus on technological resources and capabilities as drivers of a port's development has been recognized in both grey

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[1] In 2004, Rotterdam was still the world's largest port in terms of containerized (TEU) units. That year it was overtaken by Singapore, which was successively overtaken by Shanghai. As of 2020, Rotterdam is # 10 and the top 9 are located in East or South Asia (7 of them in China) (World Shipping Council, 2021).

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literature (ADB, 2020; EPRS, 2020; Jahn & Saxe, 2017) and academic studies (Inkinen, Helminen, & Saarikoski, 2021; Lam, Goh, & Pu, 2020; Parola, Satta, Buratti, & Vitellaro, 2021). Moreover, the COVID-19 pandemic has raised awareness on the importance of digitalisation adoption in supply chains in general (PwC, 2020) and seaports in particular (Deloitte and ESPO, 2021; ESCAP, 2021; Notteboom, Pallis, & Rodrigue, 2021). Despite this recognition, explanatory theory (Gregor, 2006) on the interrelation between technology and business models is scarce in maritime research and port studies (Del Giudice, Di Vaio, Hassan, & Palladino, 2021). Although many innovation studies have analysed and described the implementation of new technologies in the maritime industry and seaports, with its many benefits, challenges and opportunities (Acciaro, Renken, & El Khadiri, 2020; Ahmad, Hasan, Jayaraman, Salah, & Omar, 2021; Pu & Lam, 2021; Yang et al., 2018), few of them have addressed the mechanisms that underpin the inter-relationship between technology adoption and business model innovation in these contexts (among these few: Agrifoglio, Cannavale, Laurenza, & Metallo, 2017; Ferretti & Schiavone, 2016).

Scholars have called for studies exploring the impact of new technologies on supply chains and seaports (Dutta, Choi, Somani, & Butala, 2020; Peña Zarzuelo, Freire Soeane, & López Bermúdez, 2020; Scully & Höbig, 2019), looking to develop explanatory theory of this impact's mechanisms. Parola et al. (2021) call for research that would investigate barriers to the adoption and diffusion of digital technologies across maritime supply chains. However, a theoretical explanation of the way in which technologies affect business models is needed in order to understand what drives or impedes its adoption. While explanatory theory has been developed in this regard from a general perspective (Chesbrough, 2007; Teece, 2018), the topic needs also studies conducted in specific industry contexts, among them the maritime industry and seaports.

This research paper, therefore, aims to offer explanatory theory on the mechanisms through which Industry 4.0 technologies (like IoT and blockchain) affect business models in a seaport context, and more particularly the evolution towards a "Smart Port" model. To this end, it elaborates a conceptual model that seeks to explain the relationship between the adoption of Industry 4.0 technologies and the evolution of a seaport's business model. This conceptual model is then assessed in the light of an exploratory case study conducted on the port of Barcelona. This research extends previous work on this topic by the authors (Henríquez, Martínez de Osés, & Martínez Marín, 2020).

The research question that this paper intends to give an answer is expressed in the following way:

RQ. *How Industry 4.0 technologies might drive business model innovation in a seaport context?*

The answer to the question is in line with the exploratory nature of this study: the authors do not seek to validate hypotheses that would provide a definitive explanation, but rather to plant theoretical seeds into the ground for subsequent research.

The rest of the paper is structured as follows: Section 2 reviews literature from management science and maritime studies, including port models and technologies, as well as research on Industry 4.0 technologies and business models. Section 3 presents a conceptual model for explaining the relationship between Industry 4.0 technologies and seaport business model innovation. Section 4 explains the research methodology. Section 5 develops a case study on the port of Barcelona, focusing on its technological development in the last 5 years. Section 6 discusses the conceptual model in light of the exploratory case study presented, and Section 7 concludes the paper, discussing contributions, managerial implications, limitations and suggestions for future research.

2. Literature review

This section covers previous research on the building blocks over which the conceptual model presented in Section 3 is to be built. It delves on literature from management science, maritime studies and information systems. Given the abundance of literature on concepts like business model innovation, Industry 4.0, and technologies like IoT or blockchain, the purpose is not so much to offer a complete picture, as to provide enough theoretical background to construct the propositions that comprise the conceptual model.

2.1. *Business model innovation and technological change*

Management science has analysed the inter-relationship between technology and business for several decades, with many studies revolving around the phenomenon of innovation. One of the first useful distinctions utilised was that between *technology push* and *market* (demand/user) *pull* (Howells, 1997; Raisbeck, 1982; Zmud, 1984), according to which innovation can be predominantly driven either by science applications inventiveness or by the ever-increasing need of solving real-life problems (Johnson, Whittington, Scholes, Angwin, & Regnér, 2014).

Another classification of innovation is based on the level of impact that a new technology creates: incremental, disruptive or architectural innovation. *Incremental* innovation is related with improving the ways things are done, while keeping the core elements of a technology (e.g.: fastest or greener cars). *Disruptive* innovation, in contrast, changes the core elements and requires a new way of doing things (e.g.: digital photography). *Architectural* innovation, on the other hand, does not change the core concepts/components behind a technology, but modifies their linkage (Albert & Siggelkow, 2021; Henderson & Clark, 1990).

Innovation is also distinguished according to the *locus* in which it takes place. A first general distinction has been that between product and process innovation (Bonanno & Haworth, 1998; Fritsch & Meschede, 2001; Li, Liu, & Ren, 2006; Utterback & Abernathy, 1975; Wang, Li, Li, & Wang, 2021). *Product* innovation introduces novel devices or services into the market (e.g.: the container box). *Process* innovation is about modifying the way goods and services are produced, sold, distributed, etc. (e.g.: containerization). A more recent concept in this *locus* distinction has been *Business model* innovation, understood as a change that affects how an organization creates, distributes and captures value (e.g.: vertical integration in large transportation companies) (Chesbrough & Rosenbloom, 2002; Gassmann, Frankenberger, & Sauer, 2016; Osterwalder & Pigneur, 2010; Zott & Amit, 2007).

The inter-relationship between technology and business models has been the subject of abundant academic theory (Chesbrough, 2007; Chesbrough & Rosenbloom, 2002; Hedman & Kalling, 2003; Pateli & Giaglis, 2014; Tongur & Engwall, 2014). A mainstream idea has been that business models mediate the way that technology affects firms' performance, such that the adoption of the same technology (whether related to products or processes) can turn out into very different performance outcomes, depending on which business model is adopted by the organization (Baden-Fuller & Haefliger, 2013). Another concept used to explain this interrelationship is that of *dynamic capabilities* (Teece, 2018); here, performance is dependent on how a firm can adapt, align and implement both its technology and business model, and answer to internal or external pressures. Thus, even the adoption of technology *A* and business model *B* by two firms can result in different performance levels, depending on their respective deployment of dynamic capabilities.

All these concepts and classifications are useful for explaining the relationship between the adoption of new technologies and the evolution of business models in a particular context, like that of a seaport (Del Giudice et al., 2021). They provide largely complementary perspectives to analyse what are complex and mutually influencing processes. For the purposes of this research and the elaboration of a conceptual model, we give special attention to the above-mentioned notion of *architectural innovation*.

The concept of architectural innovation was introduced in the early nineties by Henderson and Clark (1990), who defined it as an innovation that changes the way the core components of a product or process are linked together, without changing or substituting them. The essence of architectural innovation is, therefore, the *'reconfiguration of an established system to link together existing components in a new way'* (Henderson & Clark, 1990, p. 12). A closely related distinction is that between *component* knowledge, that is, knowledge of the core components of a system; and *architectural* knowledge: knowledge of how these components are integrated into a coherent whole.

As it shall be elaborated upon in the conceptual model, both component knowledge and architectural knowledge are key factors in explaining the dynamics between emerging technologies and the evolution of ports' business models.

2.2. Industry 4.0, internet of things (IoT) and blockchain in the supply-chain industry

Industry 4.0 is a paradigm that was originated in Germany (Kagermann & Helbig, 2013), in the context of developments christened as the fourth industrial revolution (Schwab, 2016). It encompasses a series of technologies surged in the last two decades, including artificial intelligence, machine learning, robotics, 3D printing, internet of things (IoT) and blockchain technology, among others. Industry 4.0 has been mainly connected with the manufacturing industrial sector (Arnold, Kiel, & Voigt, 2016), though in recent years it has also been applied to logistics, supply-chain and transportation (Hahn, 2020; Tjahjono, Esplugues, Ares, & Pelaez, 2017). A key concept behind Industry 4.0 is that of *Cyber-Physical Systems*, understood as a convergence of physical and virtual worlds, with both dimensions mutually interacting (Lee, Bagheri, & Kao, 2015). Features such as real-time reaction, interoperability, as well as horizontal and vertical integration of operation systems, are among the Industry 4.0's features; while data is considered one of its most important resources (Ibarra, Ganzarain, & Irgatua, 2018). In the maritime industry, the adoption of emerging digital technologies like the internet of things (IoT) and cloud computing has been associated with co-creation mechanisms in operations management (Agrifoglio et al., 2017).

Among the frontier technologies (UNCTAD, 2021a) associated with Industry 4.0, IoT and blockchain are particularly relevant for seaports (Ferretti & Schiavone, 2016; Sánchez-González, Díaz-Gutiérrez, Leo, & Núñez-Rivas, 2019; Yoon, Kim, & Park, 2020). In the case of IoT, two elements define its essence: sensorization and interconnection (Yang et al., 2018). On the one hand, there has been significant progress in terms of the accuracy and reliability of devices for capturing data about physical events, like geolocation or temperature. On the other hand, these devices are increasingly interconnected through ICT networks. The combination of these two elements opens a wide array of functionalities, uses cases and business models (Chen, Xu, Liu, Hu, & Wang, 2014). In the case of a seaport, many of its processes are dependent on the availability of reliable data. This means that IoT, by improving the way that data is captured, transmitted and consumed, has the potential to increase the efficiency of existing logistic process (like stacking or truck pick-up allocation) or even allowing new ones like container tracking (Choi et al., 2017; Gnimpieba, Nait-Sidi-Moh, Durand, & Fortin, 2015).

Blockchain, or more properly, distributed ledger technology (DLT) has been mainly related with uses cases in the financial industry, like cryptocurrencies. However, its applicability in logistics and maritime supply chains is also clear (Azzi, Chamoun, & Sokhn, 2019; Bavassano, Ferrario, & Tei, 2020; Cole, Stevenson, & Aitken, 2019; Dutta et al., 2020; Kouhizadeh, Saberi, & Sarkis, 2021; Pu & Lam, 2021; Scully & Höbig, 2019; Yang, 2019). At its core, blockchain is a decentralized database where events can be digitally registered in such a way that data is immutable, and any new addition to the database has to be congruent with the latest state of the ledger. The data thus registered can provide the input of events automatically triggered by software-controlled processes (aka *smart contracts*), like ordering a payment when a cargo is received. The greatest benefit for supply-chains that blockchain technology brings is that it can serve as a decentralized depository of data about events, facilitating collaboration and transparency, and streamlining the interdependencies between logistic processes (Bai & Sarkis, 2021; Pournader, Shi, Seuring, & Koh, 2020). In the context of seaports, blockchain adoption has been associated with traceability, security and transparency (Ahmad et al., 2021; Lam et al., 2020), enhanced decision-making (Durán, Fernández-Campusano, Carrasco, Vargas, & Navarrete, 2021), reduced operational costs (Lam et al., 2020), and increased efficiency and flow coordination (Peña Zarzuelo et al., 2020; Wang, Zhen, Xiao, & Attard, 2020).

Something that Industry 4.0 and its associated technologies have in common is that they streamline —and in some cases automate— the interaction between physical and information flows. Sensorization and IoT translate physical events into data streams; blockchain provides a trusted depository of data that can trigger physical actions. Because a seaport is at its core a space where interconnected physical and information flows take place, these technologies have the potential of significantly improving performance and competitiveness. It is not surprising, therefore, that they have been related with the now popular concept of a "smart port" (Ahmad et al., 2021; Yang, 2019; Yang et al., 2018).

2.3. Fifth generation port (5G), Port 4.0, and smart port

The term "smart port" is an additional member in a family that includes "smart city", "smart building", etc. These terms refer in a general way to enhanced or outright new capabilities, enabled through digitalization, that allow for improved coordination, resource efficiency, and sustainability (Camero & Alba, 2019; Eremia, Toma, & Sanduleac, 2017). However, in a more proper sense, "smart port" is a concept to be understood in the context provided by the classification of seaports into generations and, more precisely, the fifth-generation port (5G). In the same vein, a smart port can be equated with the novel concept of Port 4.0.

2.3.1. 5G port

A fifth-generation port (5G) has been characterized as a "globalized e-port", with a prominent place as a hub in global supply chains, and featuring top ICT systems. It is, moreover, focused on community and customer-centric capabilities, with a constant strive to create new value for all its stakeholders (Inkinen et al., 2021; Lee & Lam, 2015, 2016). This enhanced orientation towards customers and community implies a significant degree of business model innovation (BMI). In the context of seaports, BMI has been associated with the evolution from a "landlord" to a "port developer" role across four areas: organization, management, technology and co-creation; as well as the development of new value-creation activities (Hollen, Van Den Bosch, & Volberda, 2013).

2.3.2. Port 4.0

A Port 4.0, on the other hand, is described as an extension of the Industry 4.0 paradigm to sea and inland ports, comprising the development and implementation of data-driven innovation (Acciaro, Renken, & El Khadiri, 2020; Inkinen et al., 2021). A key value for a Port 4.0 is integration; a value that should be created along four dimensions: 1) *Terminal* integration (e.g., crane automation, paperless processes, sensorization); 2) *Port-terminal* integration, which includes automatic data exchange between port actors; 3) *Port-stakeholder* integration, which extends automatic data exchange to external entities like city authorities; and 4) *Network* integration, which envisions automatic data exchange with the wider supply chain (Jahn et al., 2018).

In the descriptions of a 5G port or a Port 4.0, a common feature is the emphasis on information flows, rather than physical flows. Or rather, on how improvements in information flows have beneficial consequences for physical flows, not only inside the port itself, but in the whole supply chain. Another feature is the characterization of a port as both *a node* in a global network *and* itself *a network* (or ecosystem) of actors. Lee and Lam put it this way: *'A port is a kind of organic system in a national socio-economic-political system as well as the globalized economic system'* (2016, p. 187). They add shortly after: *'As a social and economic organization, a port evolves continuously, adapting to changing economic and trading patterns, new technologies, legislation and port governance system'* (*idem*). These two ideas are at the core the conceptual framework presented in the next section: 1) a port as a networked, organic entity, interconnected with a broader socio-economic system; and 2) the interaction between physical and information flows as a key component in defining a port's role and activities.

2.3.3. Characteristics of a smart port

A set of characteristics associated with the concept of a smart port can be found in the literature on smart ports, 5G ports, Ports 4.0 or, more generally, in maritime studies on port competitiveness or their digital transformation. Some of these traits are rather abstract constructs, while others refer to specific functionalities, and each of them offers a partial view on what smartness means in the context of a seaport. Below we refer to each of them.

2.3.3.1. Customer centricity. Lee and Lam (2015, 2016) and Inkinen et al. (2021) consider this to be the main feature associated with seaports at the top of the generational ladder. These ports focus on the needs of direct customers and all stakeholders as the main driver behind their day to day operations, as well as their medium and long term strategic approach (ESCAP, 2021).

2.3.3.2. New value creation. In line with customer centricity, smart ports are constantly looking to create new value for their customers and stakeholders (ESCAP, 2021; Lee & Lam, 2015, 2016). Hollen et al. (2013) identify this search for new ways of creating value as an example of business model innovation.

2.3.3.3. Port developer. Hollen et al. (2013), in a case study on the port of Rotterdam, observe an evolution from a landlord model, focused only on shipping traffic handling and land exploitation, to a more entrepreneurial approach (port developer) through co-creation with the private sector; an approach similarly observed by Lee and Lam (2015) in the port of Singapore.

2.3.3.4. Enhanced port community systems. Port community systems (PCS) have been implemented by many ports so far (Deloitte, 2017; UNCTAD, 2021b), but not all of them feature an equivalent level of sophistication. Case-studies on the ports of Hamburg (Kapkaeva, Gurzhiy, Maydanova, & Levina, 2021) and Rotterdam (Simoni, Schiavone, Risitano, Leone, & Chen, 2020) identify the enhancement of information flows through more sophisticated PCS as the core element of a successful digital transformation strategy.

2.3.3.5. Tracking, tracing and event management. A study from the Asian Development Bank on smart ports (ADB, 2020) identifies the development of data capture functionalities —including track and trace, and management of business processes upon event's information— as one of the incremental steps in the transformation towards a smart port. Track and trace functionalities are associated specially with blockchain technology and IoT (Ahmad et al., 2021; Scully & Höbig, 2019).

2.3.3.6. Strategic connectivity. The concept of strategic connectivity (SC) is proposed by Hollen (2015), referring to interactions among a seaport's internal stakeholders (intra-port SC), interactions between a port and its hinterland (hinterland-oriented national SC), with other national ports (ICT national SC), and with other ports abroad (international SC). The core idea behind the concept is that connectivity is not only enhanced through physical infrastructure, but also through strategic alignment, joint ventures with other ports, or ICT integration.

2.3.3.7. Integration with smart city. A specific phenomenon, close to the above referred strategic connectivity concept, is that of port-city integration under the "smart" paradigm. Acciaro, Renken, and El Khadiri (2020) study this integration in the context of Hamburg, noting that certain port-city governance models are more suited to create synergies between the city's and port's priorities, and that the generation of value for the city of Hamburg is a core element of the port's SmartPort strategy.

2.3.3.8. Emphasis on sustainability. Chen, Huang, Xie, Lee, and Hua (2019) study the concepts of green port and smart port, and conclude that they are mutually re-enforcing: smartness (particularly data-driven) contributes to sustainability; and the strife for more sustainable operations pushes towards the adoption of smart technologies. This mutual relationship between smartness and sustainability is also noted by ADB (2020), ESCAP (2021), and Lee and Lam (2016).

2.3.3.9. Competitive transhipment centre. Lee and Lam (2015) associate an enhanced capability of a port to attract transhipment cargo as a trait of a 5G port, a capability that is based on a customer-centric foreland strategy, in contrast with a two-dimensional price and quantity approach, proper of a 4G port.

2.3.3.10. Terminal integration, port-terminal integration, port-stakeholder integration, network integration. As observed before, these characteristics are associated with the concept of Port 4.0 (Jahn et al., 2018) Each one of them can be respectively linked with the types of strategic connectivity mentioned by Hollen (2015). Peña Zarzuelo et al. (2020) refer to these levels of integration, based on data-sharing and connectivity, as one of the main challenges for the development of a Port 4.0.

2.3.3.11. Data-driven functions. A data-driven approach to define smartness in the context of a port is also found in the literature (Acciaro, Renken, & El Khadiri, 2020, ADB, 2020; ESCAP). Wang et al. (2020) study data-driven models for improving the efficiency of ship traffic in ports, where data sharing through blockchain-technology enhances decision making in single-party, two-party and multi-party contexts. Inkinen et al. (2021) note that data sourcing and data-driven applications are at the core of the "virtual port" model, itself associated with the smart port concept.

2.3.3.12. IoT-based management processes. The design and implementation of IoT-based functionalities supporting a diverse array of processes in a seaport is associated with the smart port concept (ADB, 2020; ESCAP, 2021; Parola et al., 2021; Yang et al., 2018). The core idea is that IoT enables real-time data-flows, which in turn enhance physical flows.

2.3.3.13. Real-time data interchange. The above mentioned real-time exchange of data between actors, enabled mainly through the deployment of IoT (Acciaro, Renken, & El Khadiri, 2020; Yang et al., 2018) and blockchain technology (Pu & Lam, 2021; Wang, Liu, Wang, & Yue, 2021), is associated with the Industry 4.0 paradigm and smart ports.

2.3.3.14. Digitally-enabled port synchronization. In turn, real-time data collection and sharing makes possible an enhanced synchronization among actors in a seaport. This capability is also associated with the concept of a smart port (Ahmad et al., 2021; Jahn et al., 2018; Wang, Hu, Zhou, Zun, & Qian, 2021), exemplified in use cases like smart gates for container pick up by trucks (Ahmad et al., 2021) and the novel digital twins (Wang, Hu, et al., 2021).

As previously mentioned, in order to provide a list of "smart port characteristics", we delved into maritime studies that either expressly analysed the smart port concept, treated the fifth generation (5G) port or Port 4.0 concepts, or in general studied port competitiveness and digital transformation in a seaport context. We did not limit our search to previous definitions of smart port; instead, our goal was to gather a set of trails that would, in conjunction, provide a broad description of what "smartness" would mean in a seaport context.

The above list, therefore, is not meant to be taken as a set of "requirements" for a seaport to be considered "smart". In fact, the authors consider that smartness is a matter of degree and not a binary status (in the sense that a port would either be "smart" or "not smart"). Seaports could then be considered to have a more or less advanced degree of smartness, according to how many and to which extent they feature the above characteristics or functionalities.

Table 1 below shows the list of characteristics and the literature sources that associate them, directly or indirectly, with the concept of a smart port. Neither the list itself nor the literature mentioned are meant to be exhaustive.

3. Theoretical conceptual model

This section is divided into three sub-sections. The first one elaborates a concept of a smart port as a synthesis of the related concepts of 5G port and Port 4.0, delving into the list of characteristics shown in Table 1, and exploring what "smartness" could mean for a seaport. The second one explains two mechanisms through which Industry 4.0 technologies might drive business model innovation in a seaport. To that effect, it develops a series of propositions, which are depicted as a conceptual model in the third sub-section. This model provides a theoretical answer to the research question, an answer that is in turn assessed in the light of the case study results.

3.1. A smart port concept

3.1.1. Smart port characteristics as a network and as a node in a global network

As previously observed, a smart port can be understood along two fundamental dimensions: as an organic ecosystem, being itself a network (Lee & Lam, 2016); and as a node in the global supply network (Zuidwijk, 2018). Each of these dimensions incorporates the characteristics listed in Table 1. Table 2 below classifies those characteristics according to the dimensions.

Some differences of perspective can be seen in the concepts of 5G port and Port 4.0 and their associated characteristics. While the latter emphasizes mainly technological applications and functionalities, the former focuses more on the broad role that a port plays. The customer and community centricity of a 5G port is one of its distinguishing features; while the technical concept of integration is a key component of a Port 4.0. Likewise, at the essence of the Port 4.0 concept is the adoption of a set of frontier technologies and the pursuit of data-driven innovation; while what is mainly innovative about a 5G port is that it creates value in novel ways.

At this stage, it can be said that the concept of a 5G port describes the role that it plays towards its internal and external stakeholders, having a *market* focus. Instead, the Port 4.0 concept is built upon a list of functionalities and activities, having a *technology* focus. These two dimensions, market and technology, are the basis of the above-mentioned distinction between *technology push* and *market pull*, and provide the structure of the conceptual model.

3.1.2. What does "smartness" mean in a seaport context?

Almost two decades ago, the construct of "smart business networks" (SBN) was proposed and studied by a group of scholars associated with the Rotterdam School of Management (Vervest, Van Heck, Preiss, & Pau, 2005; Vervest, Van Heck, Preiss, & Pau, 2004). The concept was said to emerge in part from a question described as follows:

> *In August 2003 a group of the School's researchers put the following question: imagine that, all over the port of Rotterdam, one could have instant wireless access to the state of all ships, trucks, containers and cargo and to anyone and anything related to this. If so, could one manage the processes better, faster, more effectively, and more efficiently? What could one do that was not possible before? What would be required to do so?* (Vervest et al., 2004, p. 225).

Three things can be noted in the quoted description: 1) the context inside which the SBN construct surged was that of a seaport; 2) there's an immediate reference to a technology ("instant wireless access"); and 3) it can be clearly seen that smartness is linked to a series of performance qualities ("better", "faster", "more effectively", etc.) related to the interaction between information flows and physical flows.

In a different place (Vervest et al., 2005), the authors describe "smart" in the following way:

> *We apply the word "smart" to an action that is novel and different, hence thought of as innovative. Smart actions create remarkable, "better than usual" results. Smart has a connotation with fashionable and*

Table 1
List of characteristics of smart ports.

Characteristics	References
Customer centricity	ESCAP, 2021; Inkinen et al., 2021; Lee & Lam, 2015, 2016
New value creation	ESCAP, 2021; Hollen et al., 2013; Lee & Lam, 2015, 2016
Port developer	Hollen et al., 2013; Lee & Lam, 2015, 2016
Enhanced port community systems	Lee & Lam, 2015, 2016; Kapkaeva et al., 2021; Simoni et al., 2020
Tracking, tracing and event management	ADB, 2020; Ahmad et al., 2021; Scully & Höbig, 2019
Strategic connectivity	Hollen, 2015
Integration with smart city	Acciaro, Renken, & El Khadiri, 2020; Lee & Lam, 2015, 2016
Emphasis on sustainability	ADB, 2020; Chen et al., 2019; ESCAP, 2021; Lee & Lam, 2015, 2016
Competitive transhipment centre	Lee & Lam, 2015, 2016
Terminal integration	Jahn et al., 2018; Peña Zarzuelo et al., 2020
Port-terminal integration	Jahn et al., 2018; Kapkaeva et al., 2021
Port-stakeholder integration	Jahn et al., 2018; Lee & Lam, 2016; Peña Zarzuelo et al., 2020
Network integration	Jahn et al., 2018; Peña Zarzuelo et al., 2020
Data-driven functions	Acciaro, Renken, & El Khadiri, 2020; ADB, 2020; ESCAP, 2021; Inkinen et al., 2021, Wang et al., 2020
IoT-based management processes	ESCAP, 2021; Parola et al., 2021; Yang et al., 2018
Real-time data interchange	Acciaro, Renken, & El Khadiri, 2020; Pu and Lam, 2021; Wang, Liu, et al., 2021, Yang et al., 2018
Digitally-enabled port synchronization	Ahmad et al., 2021; Jahn et al., 2018; Wang, Hu, et al., 2021

Table 2
Characteristics of a smart port according to dimensions.

	5G Port	Port 4.0
Port as a network ecosystem	• Customer centricity • New value creation • Port developer • Enhanced port community systems • Tracking, tracing and event management	• Terminal integration • Port-terminal integration • Data-driven functions • IoT-based management processes
Port as a node in the global supply network	• Strategic connectivity • Integration with smart city • Emphasis on sustainability • Competitive transhipment centre	• Port-stakeholder integration • Network integration • Real-time data interchange • Digitally-enabled port synchronization

distinguished, but also with short-lived. What is smart today will be considered common tomorrow. The word "smart" in smart business networks is therefore not an absolute but a relative term. Smartness is a property whereby the network can create "better" results than other, less smart business networks, or other forms of business arrangements. While intelligence in the communications systems and networks may have a more absolute meaning, smartness of business networks is relative, time-bound and situation-bound. To be smart in business is to be smarter than the competitors, just as an athlete considered fast means (s)he is faster than the others (p. 20).

Delving into the previously quoted considerations, we propose the following understanding of what "smartness" means in a seaport:

First, the concept itself is indeed relative to time and situation circumstances. In this sense, the classification of ports into generations, precisely because it is time-bound (as years pass, new generations emerge), provides a practical way of determining what counts as a smart port: a port that is considered to be at the top of the generational ladder (currently, 5G), should be considered a smart port (or, put in a different way, a port with a high level of "smartness").

Second, smartness is very closely linked to technological capabilities and functionalities. While 20 years ago, these capabilities and functionalities were mainly about physical flows related infrastructures (i.e.: having the bigger gantry cranes or most advanced RTG container systems), now they are increasingly related to information flows (i.e.: IoT, sensorization, digital twins, real-time track and trace). Still, IT functionalities are "smart" in as much as they enable increased performance in physical flows (i.e.: more efficient handling of containers inside the yard through a digital twin; shorter pick-up times and less congestion for trucks through e-gates; etc.).

Third, smartness is about satisfying the demand for seaport services better than others. A port with the most advanced physical and technological resources and capabilities, but that does not effectively answer to what customers demand, cannot be considered "smart". An extreme hypothetical example would be, for instance, a port with a very high container handling capacity, very sophisticated IoT and event-management systems, but located in a small island in the middle of the Pacific Ocean.

These three features of "smartness" (relative, technology-linked, demand-oriented) are reflected in the conceptual model presented ahead. The technology linkage aspect is reflected in the technology push mechanism, the demand orientation aspect in the market pull mechanism, and the relativeness of the smartness concept in the time and situation boundedness of what counts as advanced technology and of what is demanded by the market.

3.2. Theoretical propositions

The research question of this paper asks how Industry 4.0 technologies might drive business model innovation in a seaport. Based on the theoretical background presented in the literature review, and following the approach adopted by previous studies on diverse industry contexts (Brem & Voigt, 2009; Geum, Jeon, & Lee, 2016; Horbach, Rammer, & Rennings, 2012; Lubik, Lim, Platts, & Minshall, 2013; Luong, Male, & Glennon, 2008), this sub-section elaborates an answer along two mechanisms of influence: technology push and market pull. Each one of them channels in a different way the influence that Industry 4.0 technologies exercise towards the adoption of a smart port business model; and each one does so in three different areas: operations, strategy, and investments.

3.2.1. Technology push

To understand the influence that the adoption of Industry 4.0 technologies by a seaport has in its business model, it is useful to refer to the above-mentioned concepts of architectural innovation, architectural knowledge and component knowledge. Every innovative technology (IoT, blockchain, VR/AR, etc.) brings with it a set of required skills and competences about the devices used, which correspond with *component* knowledge. However, as the technologies are adopted, *architectural* knowledge —defined as *'knowledge about the ways in which the components are integrated and linked together into a coherent whole'* (Henderson & Clark, 1990, p. 11)— becomes necessary. This knowledge is not limited to technological knowledge, because the components of this "coherent whole" are not just devices, but also business processes, communication protocols, etc. The result is a requirement, for a seaport that adopts Industry 4.0 technologies, to develop new capabilities and tasks or to "reengineer them" (Agrifoglio et al., 2017; Dutta et al., 2020; Inkinen et al., 2021; Lam et al., 2020; Simoni et al., 2020; Tsiulin & Reinau, 2021).

The first answering proposition to the research question can therefore be stated as follows:

P1. *Industry 4.0 technologies exercise a push towards architectural innovation in seaports, by requiring new capabilities and tasks.*

This proposition is divided into 3 ancillary propositions, according to three different areas where innovation takes place: operations, strategies, and investments.

Operations in a seaport are still, in essence, about handling physical flows (Lam et al., 2020; Parola et al., 2021). New data-driven functions like container tracking or automatic stacking are just more sophisticated ways of performing this handling (Ahmad et al., 2021; Dutta et al., 2020). As Industry 4.0 technologies are adopted in the seaport, the port provides new data-driven services that aim to increase efficiency in the interaction between physical and information flows (Jahn et al., 2018; Jahn & Saxe, 2017; Lam et al., 2020; Wang et al., 2020).

Proposition P_{1a} is thus stated as follows:

P1a. *Industry 4.0 technologies generate new data-driven services that aim to streamline the interactions between physical and information flows in the ordinary operations of a seaport.*

Strategies should be aligned with the role that a seaport aims to perform towards internal stakeholders (carriers, shippers, terminal operators, customs authority, etc.), and external ones (city council, inland ports, etc.) (Jahn et al., 2018; Wang, Hu, et al., 2021). The increased amount of data generated by the adoption of Industry 4.0 technologies is expected to exercise a pressure towards more integration with these stakeholders (Ahmad et al., 2021; Peña Zarzuelo et al., 2020; Pu & Lam, 2021; Simoni et al., 2020; Tsiulin & Reinau, 2021).

Proposition P_{1b} is thus stated as follows:

P1b. *Industry 4.0 technologies generate innovative strategies, oriented towards information integration of a seaport with its internal and external stakeholders.*

The adoption of Industry 4.0 technologies requires new ICT infrastructure, which in some cases is considerably expensive (Acciaro, Renken, & El Khadiri, 2020; Del Giudice et al., 2021; Dutta et al., 2020; Ferretti & Schiavone, 2016; Inkinen et al., 2021). Seaports are therefore expected to increase their investments in ICT infrastructure as this adoption takes place.

Proposition P_{1c} is thus stated as follows:

P1c. *Industry 4.0 technologies generate new investments in a seaport's ICT infrastructure.*

3.2.2. Market pull

The place that seaports have in global supply chains is strategic. They concentrate physical and information flows across the supply chain like no other entities.[2] As previously expressed, seaports are important *nodes* in a global network (Inkinen et al., 2021; Parola et al., 2021). The adoption of Industry 4.0 technologies by other nodes in this network, and by other important players like big shipping companies, is therefore expected to generate a market pull over all the nodes, as they become more interconnected (Bavassano et al., 2020; Lee & Lam, 2016).

The second answering proposition to the research question can be stated in the following way:

P2. *As Industry 4.0 technologies are adopted by the maritime industry as a whole, they generate a pull towards their adoption by seaports.*

As with P_1, P_2 is to be divided into 3 ancillary propositions, depending on the area where the *locus* of innovation is situated.

When shipping companies, city councils, customs authorities, etc. adopt digitalization technologies, this creates a pressure over seaports to offer data-driven services (Wang, Liu, et al., 2021). For instance, if a global shipping company offers IoT-based container tracking services, it will prefer to work with port terminals that support those services with their own data-driven capabilities (Choi et al., 2017; Yang et al., 2018).

Proposition P_{2a} is thus stated as follows:

P2a. *Seaports offer Industry 4.0-based, data driven services, as internal and external stakeholders require their provision.*

Interconnection with a port's hinterland, inland ports, city authorities, or seaports located abroad, has been mostly focused on the right physical infrastructure (Lam & Yap, 2011; Notteboom & Rodrigue, 2008). However, as Industry 4.0 technologies are adopted across global supply chains, the need for coordination, IT standards setting, integration, etc. is increased. It is to be expected, therefore, that knowledge-based collaborations between a seaport and its external stakeholders (strategic connectivity) would increase (Hollen, Van Den Bosch, & Volberda, 2015; Peña Zarzuelo et al., 2020).

Proposition P_{2b} is thus stated as follows:

P2b. *Seaports increase their focus on strategic connectivity, as a result of market pull from external stakeholders.*

In the same vein, as other global players and seaports invest in new ICT infrastructures while adopting Industry 4.0 technologies, seaports need to keep up with those investments in order to remain competitive (Allam & Newman, 2018; Cepolina & Ghiara, 2013; Jardas, Dundović, Gulić, & Ivanić, 2018; Jović, Kavran, Aksentijević, & Tijan, 2019); or as put by De Langen, Turró, Fontanet, and Caballé (2018): *"to address the challenges of the growing and changing needs of production and supply chains and to adapt to the requirements of sustainable transport"* (p. 15).

Proposition P_{2c} is thus stated as follows:

P2c. *Investments in Industry 4.0 technological infrastructure by the shipping industry, generate a competitive pull to catch up with other seaports.*

Table 3 summarizes the propositions above stated, showing the basic structure of the conceptual model. The adoption of industry 4.0 technologies in a seaport or in the whole maritime industry is the independent construct (an approach followed by Pournader et al., 2020); technology push and market pull are the influence mechanisms; and levels of innovations in the areas of operations, strategies and investments are the dependent constructs.

3.3. Conceptual model depiction

Fig. 1 depicts the conceptual model, summarizing the place of the propositions in relation to the independent construct, the influence mechanisms, the dependent constructs and the concept of smart port itself. The model sketches the influence that the adoption of Industry 4.0 technologies by seaports and the shipping industry exercises, through the mechanisms of technology push and market pull, over a seaport's operations, strategies and investments.

In turn, the innovations that take place in each of these three areas, might add up to one or more of the defining characteristics of a smart port presented in Table 2. In other words, innovations in operations, strategies and investments, whether market or technology driven, move a seaport towards the smart port concept.

Table 3
Conceptual model propositions.

	Independent construct	Industry 4.0 technologies
	Influence mechanisms	
	Technology push	Market pull
Dependent constructs	P_1 *Industry 4.0 technologies exercise a push towards architectural innovation in seaports, by requiring new capabilities and tasks*	P_2 *As Industry 4.0 technologies are adopted by the maritime industry as a whole, they generate a pull towards their adoption by seaports.*
Operations	P_{1a} *Industry 4.0 technologies generate new data-driven services that aim to streamline the interactions between physical and information flows in the ordinary operations of a seaport.*	P_{2a} *Seaports offer Industry 4.0-based, data driven services, as internal and external stakeholders require their provision.*
Strategies	P_{1b} *Industry 4.0 technologies generate innovative strategies, oriented towards information integration of a seaport with internal and external stakeholders.*	P_{2b} *Seaports increase their focus on strategic connectivity, as a result of market pull from external stakeholders.*
Investments	P_{1c} *Industry 4.0 technologies generate new investments in a seaport's ICT infrastructure.*	P_{2c} *Investments in Industry 4.0 technological infrastructure by the shipping industry, generate a competitive pull to catch up with other seaports.*

4. Research method

4.1. Case study methodology

This study follows the exploratory research methodology by conducting a case study, as has been done recently by papers in maritime and supply chain research (Pantouvakis & Syntychaki, 2021; Vural, Roso, Halldórsson, Ståhle, & Yaruta, 2020). Exploratory research and case studies have been considered appropriate for the analysis of contemporary phenomena, where empirical data from which to derive statistical inferences is not available, or not abundant enough (Benbasat, Goldstein, & Mead, 1987; Yin, 2009). Moreover, the research follows the critical realism epistemological approach, according to which there is an external, causally driven reality, independent of our empirical perceptions (Bhaskar, 1975). This reality cannot be reduced either to the observable or the measurable (positivism), or to the outcome of socially constructed meanings (interpretivism). Critical realism provides a sound epistemological basis for case studies in general (Easton, 2010), and for information systems research in particular (Mingers, Mutch, & Willcocks, 2013).

Exploratory research is useful to study emerging technologies like those associated with the Industry 4.0 paradigm (Harikannan, Vinodh, & Gurumurthy, 2021; Menon & Shah, 2020; Shin, 2017; Tu, 2018; Zhu, Shi, Huang, & Zhang, 2020). Rather than validating hypotheses or propositions, exploratory studies look to extend the theoretical and

[2] This could be stated also regarding *financial* flows. It is no coincidence that some of the largest or historically relevant ports in the world (New York, Amsterdam, Singapore, Hong Kong, Shanghai) are also global financial centers; a phenomenon interestingly explained by Kindleberger (1973).

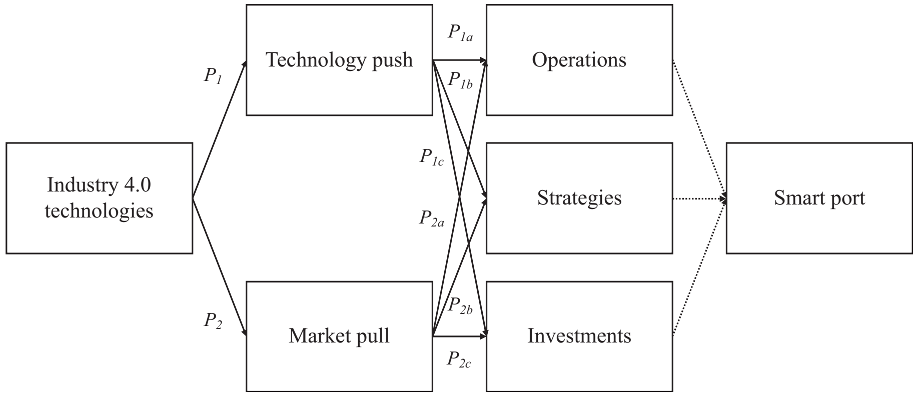

Fig. 1. Conceptual model

empirical ground over which future research might be based, including quantitative research with a positivist approach.

As previously said, this paper does not adopt the positivist (or interpretivist) approach, but rather a critical realist one (though given its qualitative nature, its methodology is closer to interpretivism). In this sense, the evaluation of the conceptual model in view of the results of the case study —which is the core of the research methodology—, does not purport to validate the propositions presented (as a positivist approach would seek), but rather, to assess whether they provide useful insights for exploring and building explanatory theory.

The use of propositions or hypotheses has been considered an appropriate way of expressing theoretical frameworks in the context of exploratory research (Casula, Rangarajan, & Shields, 2021; Yin, 2009), in contrast with grounded theory methodology, where no propositions should be stated (Glaser, 1978; Makri & Neely, 2021). In this study, the proposition-built conceptual model plays the role of an *"initial framing device (…) designed using the literature"* as Casula, Rangarajan and Shields (2021, p. 1708)put it, and serves as a *"flexible conceptual framework"* (p. 1709).

4.1.1. Choice of port of Barcelona as the exploratory case study

The subject of the case study is the port of Barcelona. The choice of Barcelona was based on several reasons. First, the port of Barcelona has experienced a considerable level of innovation in operations, strategy and investments during the last decade, which makes it particularly suitable to explore innovative trends and influence mechanisms.

Second, one of the main enquiries of this study is how benchmarking might play a role when it comes to adoption of new technologies and business models in a seaport context. Benchmarking requires both an entity that does benchmarking and another entity, considered to be a model to follow, over which benchmarking is done. While several studies have been conducted on ports that are considered at the top of technological innovation —and are usually the reference of benchmarking— like Singapore (Lam et al., 2020; Weeks, Mandal, & Sen, 2017), Rotterdam (Hollen, 2015; Simoni et al., 2020) or Hamburg (Ferretti & Schiavone, 2016; Kapkaeva et al., 2021), the authors sought to complement those with a study on a port like Barcelona which, rather than being the reference of benchmarking, is itself a case of performing benchmarking by its authorities and players.

Finally, the availability of data facilitated the research, as port authorities have been very open in documentating their strategies and initiatives.

4.2. Data sources

4.2.1. Documentary sources

Given the exploratory nature of the research, and its early stage, data gathering was predominantly from documentary sources. Three sources were accessed: 1) the Documentary Centre of the Barcelona Port Authority, 2) internet sources, particularly from the website of Piernext, and 3) audio-visual material from the annual event "Smart Ports: Piers of the Future 2020", which took place (online) in Barcelona on November 17–18, 2020.

Among the documents reviewed in the Documentary Centre, the Port of Barcelona *3rd Strategic Plan: 2015–2020* (Port de Barcelona, 2015) and the recently adopted *4th Strategic Plan 2021–2025* (Port de Barcelona, 2021) were particularly relevant. Piernext is an initiative of the Barcelona Port Authority itself (as it will be mentioned in the case study section), so its website (https://piernext.portdebarcelona.cat) constitutes a very useful source. Finally, the videos of the conferences that were presented during the above referred event, are helpful in building an updated view from experts and officials of various port authorities about the topics covered in this research. The videos and agenda of the event are accessible at its website (https://smartports.tv/2020). The use of material and data from internet sources has been considered especially suitable for case study research (Gallagher, 2019).

4.2.2. Semi-structured interview

On October 7, 2019, one of the authors conducted a semi-structured interview with a top official of the Barcelona Port Authority, related with the area of strategy and innovation. The interview lasted for about 90 min. Upon request of the interviewee, it was not recorded, but handwritten notes were taken.

The official in question was at the time of the interview the Director of Strategy and Innovation of the Barcelona Port Authority (BPA), where he is currently Chief Innovation Officer. He has been working in strategy roles at the BPA since 2006, and was directly involved in the research, discussions and implementation of both the 3rd and 4th Strategic Plans of the Port of Barcelona. In addition, the interviewee is Associated Professor of the Universitat Politècnica de Catalunya (UPC), where he has had academic positions for more than 26 years. Since 2008, he has been the Director of the Executive Master in Supply Chain Management at UPC, and since 2007, professor at the European School of Short Sea Shipping.

The authors chose to interview this official because the direct experience that he has on the strategy and management processes, as well as his ample knowledge on the port area, both in management and academic positions. It was considered that the official was one of the most suitable persons to be interviewed, since he could provide insights based on his own direct experience of the facts and events that comprise the subject of the case study: the approach that the port of Barcelona has been taken to technology, and the role this plays in operations, strategy and investments.

During 2020, other requests for interview were made, but largely due to the lockdown and limitations posed by the COVID-19 pandemic, no additional interviews could be conducted with relevant people from the port of Barcelona.

4.3. Data analysis

The data gathered about the subject of the case study is presented in Section 5 and discussed in Section 6. The exploratory case study was conducted as a way of evaluating the propositions that build the conceptual model presented in Section 3. The evaluation is done through content analysis, a technique for analysing documentary sources, which aims to provide new insights, increase a researcher's understanding of particular phenomena, or inform practical actions (Krippendorff, 2019; Weber, 1990). Each of the propositions is evaluated against a scale with four possible scores: not grounded (−), lowly grounded (+), moderately grounded (++), and highly grounded (+++). As previously observed, the assessment does not intend to "validate" in a positivistic way the conceptual model or to derive definite conclusions, but instead to increase the understanding of topics under study and provide insights for subsequent research (Casula et al., 2021; Marlow, 2005).

4.4. Research quality

Following recent exploratory case studies in the logistics field (Vural et al., 2020), the research quality of this study is evaluated through the 4 criteria of rigor proposed by Halldórson and Aastrup (2003) for qualitative research in logistic studies: credibility, transferability, dependability and confirmability.

This study's *credibility* (equivalent to internal validity in positivist research) is grounded on the "match" between the phenomena and constructions that emerge from the case study (derived from the data sources), and the theoretical propositions (presented in the conceptual model). To this end, the study evaluates the model through a discussion based on various sources of data. Given that the context of the case study is time and space bound, *transferability* (equivalent to external validity) of the findings is limited. Nonetheless, as noted by Halldórson and Aastrup (2003), this does not mean that *'knowledge acquired in one context is of no relevance for other contexts or frames of time'* (p. 327); therefore, the extent of this transferability will be explained with more detail in Sections 6 and 7, regarding representativeness of the case study and its limitations. *Dependability* (equivalent to reliability) is achieved since most of the data sources that ground the findings are stable documentary sources. In the case of the semi-structured interview, even though it could not be recorded upon the interviewee's request, detailed written notes were taken. Finally, *confirmability* (equivalent to objectivity) is grounded in the case study itself: the research does not limit itself to present the conceptual explorations of the authors, but confronts them with objective data sources gathered for the case study.

5. Case study: the port of Barcelona

This section is structured into sub-sections, covering the 3 areas of innovation under study, as dependent constructs: operations, strategy, and investments. Previously, a short background about the port of Barcelona and its representativeness is presented. The data collected from the sources above mentioned is directly referred in each one of the sub-sections.

6. Background

The port of Barcelona is the third biggest Spanish port in terms of containerized cargo, measured in twenty-foot equivalent units (TEU), with a total volume of 2.96 million TEUs in 2020, behind Valencia (5.42 million TEUs) and Algeciras (5.11 million TEUs) (Statista, 2021). It terms of cruise passengers, at 2.9 million in 2019, it was the biggest port in Europe, 7th worldwide, and 2nd worldwide excluding the Caribbean area (behind Shanghai) (Ship Technology, 2019). In terms of port authority revenues, it was the biggest port in Spain in 2018 (€173.5 million), over Valencia (€140.3 million) and Algeciras (€83.5 million) (El Mercantil, 2019).

After a sizable downturn in its cargo traffic volume in 2020, due to the COVID-19 pandemic, the port had its best first quarter ever in terms of containerized cargo, with a volume of 907,010 TEUs; a 25% increase in relation to Q1 2020 (Port de Barcelona, 2021b).

The port's direct hinterland is the region of Catalonia, in the northeast of Spain. Being located in the western Mediterranean Sea, the port serves also as a cargo gateway to southwestern Europe, especially southern France. As such, it has two main competitors in the region: Marseille and Genoa.

Table 4 shows the container throughputs of the main ports located in the western Mediterranean Sea for the year 2019:

As observed, the port of Barcelona has a container volume typical of the main ports in the region (in fact, the average throughput for 2019 among the ports above listed was 3.32 million TEU, exactly the volume of Barcelona). Notwithstanding some significant differences among western Mediterranean ports (e.g. Algeciras and Marsaxlokk are mainly transhipment hubs, while the rest mainly serve their respective hinterlands), they are frequently compared as a group with the bigger ports in northern Europe (Rotterdam, Antwerp, Hamburg, and Bremerhaven) (Musso & Parola, 2007; Notteboom, Parola, & Satta, 2019).

6.1. Operations

In the semi-structured interview, it was emphasized that the mission of the port of Barcelona is to serve its hinterland, and that is the main criteria used to define which operations and services are offered. This mission has been unaltered since the 1st Strategic Plan (elaborated in 1998), although the sustainability component was added to the wording in the 4th Strategic Plan.

While the aim of serving the hinterland has been the same, the set of services, operations, activities, and the incorporation of new technologies, have clearly evolved throughout the years. Among the novel technologies and services provided in the port, the following have been highlighted:

6.1.1. Virtual gates

This is a service, based on OCR technology, which aims to increase efficiency and accuracy in the process of container pick-up from trucks. The service has been provided in the 2 container terminals (TCB and BEST) since the beginning of the last decade. In the Smart Ports 2020 conference, the CIO of the port described a vision for an enhanced, data-driven and even data-managed system where certain processes would be automatically managed by algorithms, based on data inputs captured through sensors, cameras, etc.

6.1.2. Digital twins

The concept of a port digital twin has been discussed as a way of improving monitoring of port operations, safety and security, as well as the basis of AI-based predictive models (Wang, Hu, et al., 2021). One startup supported by the port (3D Modelling Studio), has developed a solution for measuring and classifying waste, through the creation of a digital twin of the waste.

Table 4
Container throughputs for year 2019.

Place	Country	Volume (million TEU)
Valencia	Spain	5.44
Algeciras	Spain	5.12
Barcelona	Spain	3.32
Marsaxlokk	Malta	2.72
Genoa	Italy	2.64
Gioia Tauro	Italy	2.52
Marseille	France	1.45

Source: authors' elaboration from Notteboom (2020).

6.1.3. IoT and blockchain

Two IoT technological platforms have been tested in the port: GPS and LoRaWAN. However, the deployment of use cases like container tracking or AC systems monitoring is still under development. Blockchain technology has a few mentions in the 4th Strategic Plan, in the context of digitalization trends, but so far there is not a specific use case being developed in the port. The emphasis with both IoT and blockchain is that they would increase efficiency and reduce costs.

6.1.4. Electronic documentation

The port of Barcelona has been working on the implementation of electronic standards and processes since 2003, and developed its port community system (PCS) "Portic" in 1999. Digitalization and automatization in this area has been mostly focused on the processes of container picking. In February 2018, it was decided that container pickup requests had to be transmitted electronically, and as a consequence the level of use of electronic documents in this area quickly increased from 40% to 100%.

Apart from these specific use cases, in the semi-structured interview it was observed that the trend in the port's services and operations is towards management of information flows. The Barcelona Port Authority is handling a global information flow, with increasing volumes of data, including data generated through sensors in the port's spaces. Services like Big Data analytics, predictive analytics, and information services based on an open data initiative are becoming part of what the port is to offer to its customers. Collecting data, informing, and managing data in real time will be core functions of the port, according to the interviewee.

6.2. Strategies

Something common to both the 3rd and 4th Strategic Plans of the port of Barcelona is that, in many passages, they make comparisons between the port of Barcelona and other ports in the Mediterranean zone, as well as those in the north of Europe (specially Rotterdam, Antwerp and Hamburg). There is a clear use of benchmarking as a strategic tool. However, the importance of factors and the weight of objectives changes clearly from one plan to the next. Most prominently, the 3rd plan emphasized growth as the main aspiration of the port, while the 4th plan mentions several times that growth in itself is not an end, and instead emphasizes sustainability as one of the key components in the port's mission and vision.

Regarding the positioning of the port, there is also a clear difference of emphasis between both plans. In the 3rd Strategic Plan, when analysing market trends and how the port should position itself, it is mentioned many times that the competition is not so much between ports, but between logistic chains and networks; and that these chains compete for a bigger portion of traffic volumes. The concept of "network port" *(port en xarxa)* is a central one in both documents, comprising the development of regional transport logistic corridors and inland maritime terminals across the hinterland.

In the 4th Strategic Plan, instead, when it comes to the port's positioning, the emphasis is in the concepts of *diversification* of the offer, and *differentiation*. These two concepts were mentioned several times in discussion panels by the port's Head of Strategy, during the Smart Port 2020 event. The basic idea is that digitalization and the adoption of more sophisticated technologies will commoditize ports' services; so it is particularly important to develop innovative and diversified services as a way to differentiate from the competition. Interestingly, it is stated several times, both in the 4th Strategic Plan and by the Head of Strategy in Smart Port 2020, that human capital will be in the end the big differentiator. In other words, technology alone will not differentiate, but the skills and knowledge of the people that implement and use it.

In both the 3rd and 4th Strategic Plans the development of strategic alliances is mentioned, but the 4th plan is more detailed. In this area, as was also mentioned in the semi-structured interview, the port of Barcelona has been taking part in several initiatives with other ports, most specially ChainPort, led by the port of Hamburg.

The new vision of the port of Barcelona is to become a "SMART logistic hub", the "SMARTest logistic hub in the MED". The definition of what "smart" stands for is based in 5 pillars (which correspond with the "smart" word as an acronym): Sustainable, Multimodal, Agile, Resilient and Transparent.

6.3. Investments

Despite the evolution in the strategic emphasis from growth to differentiation, when it comes to investments needed, physical infrastructures that could cope with increasing traffic and logistic demands are the main focus. In the 4th Strategic Plan, when assessing the fulfilment of the 3rd Strategic Plan's objectives, it is stated that there was a moderated success, with two exceptions: the growth in traffic volume was not as large as expected, and the train infrastructure from Barcelona to Zaragoza was not concluded. The general observation is that there still remain several physical infrastructure works to be developed. The main investments to be made, therefore, as described in the strategic objective OESE4 "develop needed infrastructures", are related to building, remodelling or enlarging of physical infrastructures like the added dock *(moll adossat)*, the energy dock, the Catalonia container dock, etc.

Nonetheless, there is mention, both in the 4th Strategic Plan, PierNext website and Smart Port 2020 event, of the development of a 5G telecommunication network that would cover both the water and land spaces of the port. More recently, in March 2021 it was announced that Telefonica (the largest telecommunication provider in Spain) will deploy a 5G network in the port spaces managed by the Dutch-based port operating company APM Terminals (Blackman, 2021). The 5G network is identified in several places as the technological basis of the IoT and digitalization services to be provided in the port, with particular reference to the virtual gates and monitoring systems.

Another intended project in the ICT field is upgrading the Portic PCS, with the aim of making it 100% cloud oriented by 2022. It is also intended for the Barcelona Port Authority to adopt an open-data approach, where the data generated in the port could be shared with digital solution providers, creating new value and services.

What stands, however, as one of the most highlighted aspects of the approach that the port of Barcelona has towards investments and technology, is the development of an innovation hub to support tech startups. Pier01 is a space developed by the port (in a XIX century warehouse building) where several start-ups are supported to develop innovative products, most of them related with digital transformation in logistics.

Apart from Pier01 as a physical space, the port launched PierNext as a "digital knowledge hub" for knowledge sharing and collaboration between the port and its community. OpenPort, and the Port 4.0 fund (created by the Spanish government) are also supporting initiatives for the startup community. Even though, as was observed in the semi-structured interview, the port has no intention in the short run of becoming an investor in the start-ups that are surging in its ecosystem, there is a clear policy of collaborating with them. The idea is for the port to promote technological innovation, not by conducting itself R&D projects, but by supporting a strong startup community that would develop innovative solutions in the area of logistics. In other words, the trial-and-error ridden process of innovation is to be undertaken by startups, which are highly adaptable and lean, and not by the port's more rigid organization.

7. Discussion

As expressed in the introduction, the aim of this research is to provide insights into the inter-relation between Industry 4.0 technologies and business models in a seaport context. To that end, a conceptual model that purports to offer an initial explanation of this interrelationship was built around a set of propositions, and an exploratory case-study was conducted in order to perform an assessment of them. This section, therefore, is structured along these propositions.

First, propositions P_1 and P_2 are evaluated; then, according to the specific innovation area (operations, strategies, investments) the corresponding pair of ancillary propositions are assessed. This is followed by a brief discussion of the role that factors like regulation, governance and funding might play in the adoption of smart port business models. Finally, we discuss what answer do the case study findings can provide to the research question posed at the beginning of this paper, with special focus on the notion of smartness.

7.1. Technology push influence on innovation

From the content analysis performed over the data sources, it is difficult to perceive a significant influence of technology push forces in the port of Barcelona's business model. The port does not look for innovation per se, and in fact does not mention research and development as an activity that belongs to the role it plays, leaving it to the startup ecosystem. However, there is an important observation made in the 4th Strategic Plan, and also by the Head of Strategy in the Smart Ports 2020 event: the significance of human capital for creating an innovative and differentiated port offer. The value provided by this human capital consists of the skills, knowledge and implementation procedures for the new technologies adopted in the port.

It could be argued that this emphasis on the human capital as the true differentiator can be understood in the light of the concepts of component and architectural knowledge. It appears that the port authorities are aware of the importance of developing these kind of knowledge (even if they do not use the concepts themselves).

Proposition P_1 is therefore moderately grounded.

7.2. Market pull influence on innovation

In contrast with technology push influence, market pull forces are clearly and pervasively present as a driver of innovation in basically all the data sources. Benchmarking of other ports (particularly from northern Europe), comparisons with other ports' offers and the aim to become the leading logistic hub of in the Mediterranean are market-oriented perspectives and objectives. Moreover, the orientation towards customers' needs is a core aspect of the port's mission.

The adoption of technologies and use cases like IoT, OCR, virtual gates, etc. is seen as a way of diversifying and differentiating the port's value proposition and escape commoditization. The port's authorities seem very conscious of the increasing competitive forces that will affect supply chain operators at a global level. There was a change of emphasis, from growth and capturing traffic as aims in the 3rd Strategic Plan, to a more sophisticated supply of services, including advanced technologies, in the 4th Strategic Plan. But what remains constant is the focus and orientation towards what the market is demanding.

Proposition P_2 is therefore highly grounded.

7.3. Technology and operations

From the discussions held in the semi-structured interview, as well as the content of the documentary sources, it can be seen that the port of Barcelona is envisioning and, in some cases, already performing data-driven functions. The virtual gate is a good example of a current data-driven service, which in the future is expected to depend more on the use of artificial intelligence, IoT and predictive analytics. It is, moreover, a clear example of how the management of information flows streamlines physical flows (i.e., the container pickup by trucks).

Proposition P_{1a} is then highly grounded.

While it is clear that the port looks to develop a data-driven or data-oriented set of services as a way of differentiating the port's offer, it does not appear from the data sources a strong demand from the port's community of these services. There is a mention to SMEs, as well as retailers from the Barcelona area as interested parties in the provision of data services; but the market pull forces appear more connected with the competition rather than the port's clients.

Proposition P_{2a} is then just moderately grounded.

7.4. Technology and strategies

The concept of integration with internal and external stakeholders, which is key in the Port 4.0 literature definitions above referred, is present in both 3rd and 4th Strategic Plans. The open data initiative to be followed by the Port Authority, which aims to facilitate the creation of added value from the data it collects and manages, can be said to be a form of information integration with external stakeholders. Nonetheless, this policy does not appear to be a consequence of the adoption of Industry 4.0 technologies like IoT. The integration with other ports and logistic operators is still more focused on physical infrastructures like railway lines, rather than information or IT integration.

Proposition P_{1b} is lowly grounded.

Regarding strategic connectivity, the collaboration with other ports through initiatives like ChainPort is a clear example. The Smart Port annual event itself is a collaboration with the ports of Hamburg, Antwerp, Rotterdam, Busan, Montreal and Los Angeles. Still, in the case of Barcelona, the main focus regarding collaboration with external stakeholders is on structural connectivity, particularly with those integrated in the network port *(port en xarxa)* concept, like inland ports and logistic centres.

Proposition P_{2b} is moderately grounded.

7.5. Technology and investments

In the particular case of the port of Barcelona, as mentioned, the main investments are those related to physical infrastructures. The 5G telecommunication network, however, is a case of an ICT infrastructure investment, as a way of boosting the development of IoT use cases. If the support of the startup ecosystem in Pier01 and the other initiatives is understood as a sort of "indirect" investment, then it can be said that there is an increasing focus, though still secondary, on ICT and knowledge intensive investments.

Proposition P_{1c} is moderately grounded.

As was observed in general regarding the market pull influence mechanism, there appears to be a clear focus by the port of Barcelona authorities in keeping up with the industry trends regarding new technologies. The expectation is that digitalization technologies will be widely adopted by the ports in the region, such that in order to be a leading port, Barcelona has to innovate and develop a skilled workforce. While, at least in the immediate future, most investments in the port of Barcelona are focused on the physical infrastructure, the market pull forces in terms of investment from other seaports or industry players are expected to accelerate ICT and knowledge intensive investments.

Proposition P_{2c} is highly grounded.

Table 5 summarizes the results of the conceptual model propositions' evaluation.

7.6. Regulation, governance and funding factors

While the main focus of this paper has been on the technology push and market pull mechanisms as drivers of the smart port business model, it is appropriate to discuss other influencing factors that act as either hurdles or catalysts for the adoption of this model: regulation, governance and funding.

Appropriate regulation and governance have been considered key factors that either facilitate or impede the adoption of new technologies in the maritime industry (Acciaro, Renken, & El Khadiri, 2020; Bavassano et al., 2020; Inkinen et al., 2021; Lam et al., 2020), especially in the

Table 5
Conceptual model propositions' evaluation results.

N°	Proposition	Evaluation
P_1	Industry 4.0 technologies exercise a push towards architectural innovation, by requiring new capabilities and tasks.	+ +
P_2	As Industry 4.0 technologies are adopted by the shipping industry as a whole, they generate a pull towards their adoption by seaports.	+ + +
P_{1a}	Industry 4.0 technologies generate new data-driven functions that aim to streamline the interactions between physical and information flows in the ordinary operations of a seaport.	+ + +
P_{2a}	Seaports offer Industry 4.0-based, data driven services, as internal and external stakeholders require their provision.	+ +
P_{1b}	Industry 4.0 technologies generate innovative strategies, oriented towards information integration with internal and external stakeholders.	+
P_{2b}	Seaports increase their focus on strategic connectivity, as a result of market pull from external stakeholders.	+ +
P_{1c}	Industry 4.0 technologies generate new investments in ICT infrastructure.	+ +
P_{2c}	Investments in Industry 4.0 technological infrastructure by the shipping industry, generate a competitive pull to catch up with other seaports.	+ + +

case of blockchain technology, with its decentralized architecture (Ahmad et al., 2021; Pu & Lam, 2021; Yang, 2019). Particular emphasis is being given, in this sense, to data ownership and privacy, where legal frameworks should strike the right balance between protecting privacy and stimulating information sharing (Ahmad et al., 2021; Bavassano et al., 2020). The governance model assumed by a seaport can also affect the way technology and business model innovation is adopted, though no conclusion has been reached as to whether a public, private or mixed model is preferable (Brooks, Cullinane, & Pallis, 2017; Simoni et al., 2020).

Regarding funding, De Langen et al. (2018), in a report prepared for the European Sea Ports Organization (ESPO), point out the need to count with public funding beyond the budget of port authorities, especially in those cases where the societal value creation (the "value case") cannot be (fully) captured through the port's income (the "business case").

The data analysed in the case study do not offer much information on how these factors are considered in the context of the port of Barcelona. The 3rd Strategic Plan, when describing the role of the Barcelona Port Authority (BPA), states that *'the function of the APB (…) is the management of direct services, the regulation and control of concessioned and authorized services, and the coordination, efficiency measure and leadership of the whole port services'* (Port de Barcelona, 2015, p. 64), a description closer to the landlord governance model prevalent in European ports (Brooks et al., 2017). Regarding funding, the 3rd Strategic Plan points out that the funding of investments made by the BPA is done with its own cash flow, and through complementary funding from the European Union. The 4th Strategic Plan, on the other hand, does not provide insights into either governance or funding issues. Neither the 3rd nor the 4th Plan discuss regulatory issues in relation to technology adoption.

This absence reflects a stance of the BPA that presumably gives low importance or priority to regulatory, governance and funding factors, at least when it comes to strategy planning. There is, however, an observation made in the 3rd Strategic Plan that might give some light on the approach to be taken regarding infrastructure investment funding. It is said that *"this funding of the expansion of the Port of Barcelona maintains a good level of balance between public and private investment; the public is destined basically to infrastructure, and the private to superstructures, facilities and manipulation equipment"* (Port de Barcelona, 2015, p. 66).

While it is not totally clear whether ICT would fall into the "infrastructure" or "superstructures" category, the emphasis on physical infrastructures that pervades both the 3rd and 4th Plans might point towards a categorization of ICT as superstructure, where private investment would play the leading role.

7.7. How smart is the port of Barcelona and what can be derived from its case study?

The research question of this study asks how Industry 4.0 technologies might drive the adoption of new business models by seaports. Another way of posing this question would be to ask whether the implementation of these technologies makes seaports to adopt smarter models.

This paper seeks to explore answers to these enquiries by extracting insights from the example provided by the port of Barcelona. The main answer has been the evaluation of the conceptual model's propositions summarized in Table 5, which in the case of Barcelona points towards a primacy of market pull drivers over technology push ones. But another way of deriving insights is by answering the following question: how smart is the port of Barcelona?

Assessing the port of Barcelona against the "smart port" characteristics listed in Table 1 and organized in Table 2, we find 4 main traits that point towards a significant level of smartness: 1) a conscious effort in understanding the needs of the port's clients and stakeholders (a customer centric focus); 2) an emphasis in generating value for its hinterland and the city of Barcelona (new value creation, integration with smart city); 3) supporting innovation by promoting a startup hub inside the port's ecosystem (port developer); and 4) the implementation of certain data-driven functionalities like virtual gates (data-driven functions, real time data interchange, digitally-enabled port synchronization). On the other hand, besides the said virtual gates, Industry 4.0 related functionalities are still more a matter of vision and planning, and less of actual implementation.

Assessing a specific level of smartness for the port of Barcelona is not possible, because there is simply not a scale for that[3]; all that can be said is that some of the characteristics and functionalities associated with the concept of a smart port are present.

Another way of questioning about smartness is through a comparative approach. Given that the implementation of Industry 4.0 related technologies is still fairly limited, does that mean, for instance, that the port of Barcelona is less "smart" than ports that have already implemented more of these functionalities, like some ports in the north of Europe?

If being smart is simply understood as the adoption of certain Industry 4.0, data-driven functionalities, the answer is a clear yes. However, the case study gives indications that, at least in the case of Barcelona, the quest for smartness might not be focused on simply adopting a set of technologies, but on achieving a "match" between the resources and capabilities possessed (among them, technological ones) and what the market requires. In other words, an alignment between customer centric focus and technology sophistication. Determining to which extent has the port of Barcelona actually achieved this alignment is something that goes beyond the objective of this study.

A way of answering the research question of this paper, in light of the findings of the case study, is as follows:

> For a seaport, being smart is about understanding the needs of its hinterland clients and stakeholders, and addressing those with the right set of resources and capabilities, among them technological ones. The development and adoption of Industry 4.0 technologies by the maritime industry generates pressure on seaports to adopt them as a result of benchmarking of other ports, and of more demanding clients and stakeholders. Therefore, market pull forces are the main driver towards the adoption of smarter business models by seaports.

Given the exploratory nature of this study, the above answer cannot (and it is not intended to) be conclusive. As was pointed out in Section 4,

[3] We deem to be highly questionable whether constructing one would be relevant or worthwhile.

the purpose of exploratory studies is not to validate propositions or hypotheses, but to extend the theoretical and empirical ground of a field or topic, providing basis for future research. According to Bacharach (1989) *'the primary goal of a theory is to answer the questions of how, when, and why, unlike the goal of description, which is to answer the question of what'* (p. 498). We have explored why and when do seaports adopt or implement Industry 4.0 technologies, and how those technologies might affect their business models. An increased understanding of these topics, even if it does not amount to definitive explanatory theory, can be the basis of further enquiries, whether positivistic or interpretivist. This is the contribution intended by this study.

A closely related issue is to which extent do the findings in the case study provide ground to the answer above given; how representative is the port of Barcelona of what is happening in the market?

Our answer is that no single port can be representative of what is happening in the market. What "smartness" mean for a seaport varies according to the circumstances and contexts it faces. In this sense, insights and conclusions derived from studying a specific seaport can be transferred to other ports with a similar context or set of circumstances, but not otherwise.

The port of Barcelona faces a similar set of internal and external circumstances than other ports in the Western Mediterranean, most particularly Marseille and Genoa: they are located in the same maritime route and serve an overlapping hinterland. In contrasts, other ports in the same region, like Algeciras or Marsaxlokk, are transhipment hubs; for them, what counts as being smart is expected to differ. Nonetheless, even for ports with different contexts, the insights gained from the case study can be equally relevant —if not properly transferable (Halldórson & Aastrup, 2003)—, for instance, in order to determine how their own "smart" set of data-driven functionalities or technological capabilities should be different or similar.

In its report titled *Smart Ports in the Pacific*, the Asian Development Bank observes the following regarding smartness:

> *Any port can become smarter. There is no limit in terms of port size for the implementation of smarter solutions. But this does not mean that all ports require the same level of "smartness." The appropriate level of smart port maturity and sophistication should be designed according to the needs of each individual port* (ADB, 2020, p. x).

We consider that only a piecemeal approach, that studies ports under different contexts and dynamics, can build an integral theory of what a smart port or smartness means for the whole market. This study intends to contribute to that endeavour with an individual piece.

8. Conclusion

This research paper has sought to add new insights on the interrelationship between Industry 4.0 technologies and the evolution of business models in the context of seaports. To that end, it built a conceptual model of the influence that Industry 4.0 technologies might have over innovation areas like operations, strategies and investments. In order to assess this conceptual model, it conducted an exploratory case study on the port of Barcelona. The main conclusion extracted from the case study is that, at least in the context provided by the port of Barcelona, Industry 4.0 influences business models predominantly through market pull mechanisms, as the port tries to keep up with developments in the industry, other ports, and their stakeholders.

8.1. Theoretical contributions

From a theoretical perspective, the paper extends the literature on ports models, elaborating a definition of the smart port concept, derived from the related concepts of fifth generation (5G) port and Port 4.0. The paper also contributes to the understanding of what "smartness" means in a seaport context, concluding than being smart is about finding a match between the market needs and the right set of technological functionalities, rather than by adopting a pre-defined set of technologies for its own sake. It also provides insights regarding the impact that technology push and market pull forces might have for seaports, concluding that market pull appears to be the main driver, according to the findings derived from the case study.

8.2. Managerial implications

From a managerial perspective, the paper serves not only to evaluate the conceptual model that explains the influence of Industry 4.0 technologies on the adoption of a more sophisticated business model for a seaport, but also shows how prevalent is benchmarking and market pull when it comes to adopting new technologies.

Seaports should strive to become "smarter", not as a matter of pure benchmarking, but as a result of a better understanding of the market in terms of customers' needs, and an increased integration with stakeholders like cities, logistic operators, or even other ports. This understanding and integration then helps port authorities to find the match between what the market needs and the set of technologies to be implemented, strategies to be adopted, and investments to be made.

In order to define what "smartness" requires for a specific seaport, port authorities and other port stakeholders should not overuse benchmarking (which in many cases is done in reference to ports that face different contexts). Instead, they should also adopt a more pro-active stance and develop innovative use cases, not as a way of keeping pace with technologies generally adopted in the industry, but as a way of "striving for appropriate smartness" (ADB, 2020); that is: achieving a higher degree of match between what they offer and what is really valuable to their clients and stakeholders. This proactiveness is in fact observed by Cepolina and Ghiara (2013): *"Port authorities around the world are modifying their nature and their role, acquiring more and more an active role in the governance of logistics systems and often adopting managerial and entrepreneurial behaviors"* (p. 204).

Another way of becoming smarter is through catalysing the development of component and architectural knowledge (Henderson & Clark, 1990) of Industry 4.0 technologies; that is, by acquiring and furthering the skills and competences that these technologies require, and understanding their linkages.

8.3. Limitations and suggestions for further research

The research has several limitations. First, the case study covers only the experience of the port of Barcelona. This limits the transferability of the assessment to ports that face a similar context and set of circumstances. As previously mentioned, however, the limited representativeness of the case study does not preclude for its insights to be relevant in different contexts. Second, the data sources were limited, as was the possibility of conducting additional interviews with officials from the port authority, the port's stakeholders and the port community. This limitation reduced the possibility of triangulating findings from multiple sources, something that also decreases transferability. Third, the novelty of Industry 4.0 technologies means that their implementation in the port of Barcelona is still relatively scarce, and they are more present in ideas and visions than in real and concrete use cases. This limits their analysis to what is found in statements, strategies and policies, rather than in actual developments. Finally, the nature itself of the research, as an exploratory study, implies a limited outcome in terms of explanatory theory generation. Nonetheless, the exploration conducted on the basis of a specific case study sets the grounds for more overarching theoretical understandings, under the piecemeal approach here proposed.

In line with this piecemeal approach, future studies can include experiences from other ports in the Mediterranean and North European regions, as well as in the Asian and American continents. Their strategies regarding innovation, their investments in technology infrastructures, and their definition of the right set of functionalities to be implemented, could be compared through a multi-case study research. Additionally, the influence that institutional initiatives like China's Belt and Road might have in the adoption of technologies and the development of strategic connectivity between ports, could be included in case studies. Last but not least, the regulatory, governance and funding factors previously mentioned, can be made the focus of further research on the interrelationship between technology and business models in a seaport context. In other words, in the same way that technology push and market pull mechanisms have been analysed here as driving mechanisms, further studies can focus on how regulations, governance models and funding factors boost or hamper seaports in their strive for smartness.

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Declaration of Competing Interest

None.

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