



Designing for Scale: Legal, Funding and Ecosystem Instruments for Port Innovation in Spain

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ABSTRACT

Port authorities sit at the intersection of public policy, complex logistics, and rapid technological change. While innovation is widely recognised as essential for competitiveness and sustainability, turning ideas into operational solutions depends less on the technology itself than on the institutional tools that enable adoption and scaling. This paper explores the mechanisms available to port authorities to bring innovation into practice, and how these can be combined to move from pilot projects to full operational deployment. It analyses key legal, funding, and ecosystem instruments, including public procurement frameworks and innovation funding programmes. Based on a structured review of legislation, sectoral initiatives, and national guidance on Public Procurement of Innovation, the study shows how these instruments can interact to reduce risk and support scaling beyond the pilot phase. The paper offers a structured overview of the innovation tools available to port authorities and highlights key gaps in the current framework, such as misalignment between funding and procurement cycles, regulatory rigidities, and coordination challenges, ultimately providing a strategic perspective on how port innovation systems can better support effective implementation and scale.

1. Introduction.

Ports and maritime logistics are undergoing a critical phase of rapid innovation and digital transformation. Around the world, port authorities and stakeholders are investing in new technologies, digital platforms, and smart infrastructure to improve efficiency, sustainability, and competitiveness in global supply chains. Innovation is widely recognised as a key driver of long-term competitiveness and environmental performance, and the push towards “smart port” or “Port 4.0” initiatives reflects the sector’s strong appetite for modernisation and digital integration (Brunila et al., 2021). Common drivers include the need to streamline operations, increasing regulatory pressure on envi-

ronmental performance, and the search for strategic advantages in a fast-evolving shipping landscape.

Yet moving from concept to implementation remains challenging. Many ports face the so-called “pilot trap”: a proliferation of pilot projects that fail to reach full-scale deployment. While ideation and prototyping are thriving, translating successful pilots into routine operations continues to be a systemic bottleneck.

The Spanish port system provides a particularly illustrative case. Spain’s 46 major ports, managed by 28 autonomous port authorities under the coordination of Puertos del Estado, have developed a highly active innovation ecosystem. Since 2020, the national Puertos 4.0 programme (Orden TMA/702/2020, 2020) has funded around 200 projects and pilot initiatives, with the latest call for ideas registering an 88.5% increase in proposals (Puertos del Estado, 2026). Many port authorities actively promote living labs, sandboxes, and pilot environments to test new solutions. However, only a small share of these innovations reach full operational deployment. Promising solutions

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often remain at pilot stage and are rarely reflected later in tender processes or long-term service contracts.

This gap raises the central research question: why does port innovation often stall at the scaling stage rather than at ideation, and how do legal frameworks, funding programmes, and innovation ecosystem instruments shape the transition from pilot to full implementation?

To address this question, the study examines how key institutional mechanisms in the Spanish port sector, particularly public procurement law, innovation-oriented procurement tools, national and European funding programmes, and ecosystem initiatives, affect each phase of the innovation lifecycle, from problem definition to large-scale deployment. Spain is treated as an in-depth case: its coordinated governance model and strong innovation activity make it a valuable example rather than an isolated case. By analysing the interaction between legal, financial, and ecosystem instruments, the study identifies the factors that enable, or constrain, the scaling of port innovation.

2. Literature review.

The last decade has seen extensive research on digital innovation in ports and maritime logistics. Several studies (Brunila et al., 2021; Belmoukari et al., 2023; Sakita et al., 2024) document the rise of “smart port” concepts, the adoption of digital technologies, and the potential benefits of digitalisation for efficiency, sustainability, and competitiveness. This body of work shows that ports are actively pursuing digital transformation, integrating technologies such as port community systems, Internet of Things (IoT) platforms, and automation, while building increasingly strong innovation ecosystems. For instance, a systematic review by Sakita et al. (2024) identifies key drivers, barriers, and enablers, highlighting the importance of top management support, stakeholder engagement, and the regulatory environment. Similarly, research on Spanish ports finds a “medium-high” level of digitalisation, but also points to persistent organisational and coordination challenges: technology needs to be adopted in an integrated and collaborative way across the port community to deliver real smart port benefits (González-Cancelas et al., 2020). This aligns with Brunila et al. (2021), who emphasise interoperability across stakeholders and a clear strategic vision as critical success factors.

Despite this progress, the literature also points to structural obstacles that hinder implementation and scaling. Research on public procurement and innovation highlights how bureaucratic constraints and risk aversion in the public sector can limit the adoption of new solutions (Uyarra et al., 2014). Suppliers report barriers such as overly prescriptive tender requirements, limited interaction with procurers, insufficient procurement expertise, and lengthy procedures, all of which discourage participation, particularly from smaller, innovative firms. In the port context, these challenges are compounded by sector-specific issues, including the need for multi-actor coordination and technical interoperability, which make large-scale deployment inherently complex (Carlan et al., 2016; Acciaro et al., 2018). Recent studies suggest that while ports are effective at generating pilot projects, they face greater difficulty in adoption and

diffusion, often due to institutional and regulatory constraints (González-Cancelas et al., 2020; Brunila et al., 2021). The Spanish case illustrates this clearly: even with significant investment in pilot programmes, the transition to regular services remains limited. Overall, the literature provides solid insights into how innovation is generated, but pays less attention to how it is scaled and embedded in operations.

To better understand where innovations succeed or stall, it is useful to frame the process through the innovation lifecycle, as outlined in standards such as ISO 56002. This typically moves from problem definition and ideation to solution development, pilot testing under operational conditions, and finally deployment at scale. Each phase involves different drivers and constraints. In ports, the early stages are relatively well understood, with ample research on how innovations are conceived and tested. By contrast, the final stage, where solutions must be institutionalised through contracts, budgets, and organisational change, remains less explored. As noted in previous studies, this creates a “missing link” in understanding how innovation can be sustained over time in port contexts (Brunila et al., 2021; Belmoukari et al., 2023; Sooprayen et al., 2024). Addressing this gap requires a closer look at how legal frameworks, procurement practices, and funding programmes shape the transition from pilot to full implementation.

Building on this review, a clear research gap emerges: the lack of structured approaches to explain how port innovations move from pilot to full deployment in real operational settings. While much is known about how ports generate and test ideas, far less is understood about what happens next, how successful pilots become part of routine operations and remain viable in the long term. If innovation in ports is not failing at ideation, but at implementation and scaling, attention must shift to the mechanisms that govern this transition.

This study therefore pursues four main objectives: (1) to identify and classify the main innovation instruments in the Spanish port system, particularly legal (regulatory and procurement - related), funding, and ecosystem mechanisms; (2) to analyse their strengths and structural limitations in supporting the transition from pilots to deployment; (3) to map these instruments across the innovation lifecycle to identify where support is strong and where gaps persist; and (4) to propose a more coherent pathway, including strategic recommendations, to better enable the progression from pilot trials to scaling in ports. In doing so, the study aims to move beyond a descriptive view of port innovation towards a more operational perspective on how to design for scale.

3. Methodology.

To address these questions, the study adopts a qualitative, multi-method research design. It begins with a systematic review of academic literature on port innovation and digital transformation, followed by a structured analysis of innovation instruments relevant to the Spanish port context. Two main categories are examined: legal frameworks, particularly Spain’s public procurement law and innovation-oriented procurement

policies, and funding programmes, including the Puertos 4.0 fund and key European Union schemes.

The analysis draws on legislation and official policy documents, such as the Spanish Public Sector Contracts Law (from now on LCSP) (BOE-A-2017-12902 Ley 9/2017), national guidelines on Public Procurement of Innovation (European Commission, 2018), the regulatory framework of Puertos 4.0, and European funding programmes from 2021 onwards. Each instrument is analysed in terms of its purpose, operational mechanism, and role within the innovation process.

Finally, all identified instruments are mapped against the stages of the port innovation lifecycle, using ISO 56002 as a reference model for a structured innovation process. This mapping helps clarify the phase(s) at which each instrument operates (e.g. problem identification, R&D and prototyping, pilot testing, deployment) and highlights potential imbalances or discontinuities in support across the lifecycle.

4. Results.

The analysis identifies a set of key instruments shaping port innovation in Spain, which can be broadly grouped into legal and procurement frameworks, innovation-oriented procurement processes, national funding programmes, and EU funding mechanisms.

At the centre of the scaling process is the LCSP, which acts as the main mechanism through which validated innovations are translated into operational reality. Procurement under the LCSP enables the formalisation of long-term service contracts, defining performance obligations, service levels, and continuity requirements, making it essential for scaling. At the same time, it introduces structural constraints: stringent financial and technical solvency requirements often exclude startups as lead bidders, procedures are lengthy and resource-intensive, and risk-averse behaviour is reinforced by the legal emphasis on compliance and certainty. While the law allows for proportional and innovation-friendly criteria, in practice their effect depends heavily on how contracting authorities design tenders and evaluation models.

Innovation-oriented procurement instruments, grouped under Public Procurement of Innovation (PPI), aim to address some of these limitations by explicitly dealing with uncertainty. They enable early market engagement, outcome-based specifications, and staged procurement models that link development phases with future acquisition. In theory, they provide a clear bridge between piloting and deployment. In practice, however, PPI requires a high level of institutional maturity: contracting authorities must combine technical, legal, and market expertise, invest significant effort in preparation and governance, and manage issues such as intellectual property and risk-sharing (Aschhoff & Sofka, 2009; Uyerra et al., 2014). These requirements have limited widespread uptake, and PPI does not fully resolve supplier eligibility constraints, as startups often still need to participate through consortia to meet solvency thresholds.

National innovation funding, particularly through the *Puertos 4.0* programme (Orden TMA/702/2020, 2020), plays a key

role in the early and intermediate stages of the innovation lifecycle. Its main strength lies in de-risking innovation by financing ideation, development, and piloting, while embedding solutions in real port environments through the involvement of port authorities. This has generated a high volume of technically mature pilots and strengthened links between startups and ports. However, *Puertos 4.0* is structurally disconnected from operational deployment: it does not create service contracts, guarantee continuity, or secure long-term budgets. As a result, many projects reach technical validation but stall once funding ends, reinforcing the “pilot trap”, particularly when procurement has not been considered from the outset.

European funding instruments, including CEF Transport, Horizon Europe, and ERDF (Regulation (EU) 2021/1058, 2021), reinforce this pattern at a larger scale. They provide substantial resources for research, development, and large-scale demonstrations, often through multinational consortia, and have played a key role in advancing digital and infrastructural innovation in ports. However, their focus remains on development and demonstration within fixed project timeframes. Operational integration, maintenance, and long-term exploitation are typically not covered, leaving port authorities responsible for securing follow-on procurement and budgets once projects end. As a result, EU funding supports innovation creation, but does not address scaling on its own.

Taken together, these instruments form a dense and well-resourced ecosystem for generating and validating port innovation, but one that is structurally imbalanced. Support is strongest in the early and pilot phases, while deployment and scaling depend almost entirely on procurement readiness under the LCSP. The success of scaling therefore depends less on technological maturity than on the early alignment between funding, procurement strategy, and supplier feasibility.

Mapping these instruments onto the innovation lifecycle (following ISO 56002) further highlights this imbalance. Early stages, problem identification and concept development, are well supported through ecosystem tools and early market engagement (e.g. LCSP Article 115 or *Puertos 4.0* idea calls). Prototype development and pilot validation are also covered through national and EU funding, as well as small-scale procurement mechanisms. However, at the deployment and scaling stage, responsibility shifts almost entirely to formal procurement under the LCSP, sometimes complemented by PPI approaches. For projects developed under EU funding, port authorities must typically secure budgets and launch separate tenders to integrate solutions into operations, including exploitation rights and maintenance.

This concentration of effort at the final stage helps explain why many innovations fail to progress. Scaling requires more than a functioning prototype: it depends on clear specifications, viable business models, organisational alignment, a capable supplier base, and, above all, a procurement strategy that translates pilots into contracts. If these elements are not considered early on, even technically successful pilots can stall before becoming operational services. In this sense, the challenge of scaling is not primarily technological, but institutional and structural.

Figure 1: Instrument coverage by innovation stage.



Source: Authors.

5. Discussion and conclusions.

The findings of this study resonate with broader international debates on why innovation often struggles to scale, particularly in public-sector and complex ecosystem contexts. The “pilot-to-scale” dilemma observed in ports mirrors the well-documented “valley of death” in innovation management, where projects stall between successful demonstration and widespread adoption (Ellwood et al., 2022). Evidence from the Spanish case confirms that the main barrier to scaling is not technological, but institutional. This is consistent with the public procurement for innovation literature, which highlights organisational silos, regulatory rigidity and risk aversion as persistent obstacles to the uptake of innovative solutions (Uyarra et al., 2014). Without deliberate mechanisms linking experimental phases to formal operational processes, even technically successful innovations risk remaining isolated pilots.

The Spanish port system illustrates both progress and persistent limitations. On the one hand, the coordinated governance model led by Puertos del Estado, together with programmes such as *Puertos 4.0*, has created a dynamic innovation ecosystem and a strong pipeline of prototypes and pilot projects. This reflects a broader shift towards open innovation in port clusters, in line with international trends (Mendes Constante et al., 2023; Sabino et al., 2025). On the other hand, the transition to scale remains the weakest point, largely due to misalignment between funding instruments and procurement frameworks. Early-stage innovation is supported through grants, incubators and pilot programmes operating on timelines and objectives that are not well aligned with procurement processes and budget cycles. Similar patterns have been identified by international policy bodies, which point out that innovation policy tends to priori-

tise R&D and demonstration, while procurement and regulatory frameworks lag behind in enabling adoption (OECD, 2017).

From a theoretical perspective, this study contributes by foregrounding the concept of *procurement readiness* in port innovation. Beyond technology readiness levels (TRLs), the findings suggest that procurement strategies, market conditions and institutional capacity need to be developed in parallel with technical solutions. In the Spanish case, several mature digital solutions became effectively stranded after pilot completion because port authorities lacked a predefined contractual pathway compatible with the LCSP framework. This reinforces existing evidence that procedural and organisational barriers within public procurement systems significantly constrain innovation uptake (Uyarra et al., 2014). The results also align with recent calls for more integrated innovation ecosystems, where regulators, port authorities, technology providers and funding bodies coordinate early to ensure that solutions are not only technically viable, but also institutionally adoptable (Polydoropoulou et al., 2025).

These insights have clear practical implications. To move beyond the pilot trap, port authorities need to design innovation processes with scaling in mind from the outset. This means embedding regulatory and procurement considerations into pilot design, and making use of existing flexibilities, such as preliminary market consultations and innovation-oriented procurement procedures, to align experimentation with future contracting needs. Stronger coordination between procurement timelines, budget cycles and funding programmes is also essential to allow successful pilots to transition into operations without significant delays.

Policy adjustments could further support this alignment. Public procurement frameworks could be refined to lower barriers for smaller and newer firms and to provide clearer guidance on the use of innovation partnerships or phased contracting for novel technologies (Georgiou et al., 2014; Uyarra et al., 2014; OECD, 2017). National and European funding bodies could also consider allocating resources specifically for post-pilot scaling, including early commercial deployments and procurement-related costs. Incorporating procurement readiness considerations alongside TRLs would help ensure that projects are prepared for operational integration. At the same time, innovation ecosystems such as living labs, accelerators and public-private partnerships remain critical not only for generating ideas, but also for building trust, reducing information asymmetries and managing risk through early engagement of end users and regulators (Mendes Constante et al., 2023).

In conclusion, the Spanish case shows that effective port innovation requires a lifecycle approach. Aligning legal, funding and ecosystem instruments within a coherent innovation strategy can prevent promising pilots from remaining isolated experiments and support their transition into scalable solutions. Designing for scale, by integrating procurement and market considerations from the beginning, offers a clear pathway to closing the implementation gap in ports, both in Spain and beyond.

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