

# BUSINESS MODEL TRANSITION OF MARITIME AUTONOMOUS SURFACE SHIPS: NICHE INNOVATION OSCILLATING BETWEEN INSTITUTIONAL PRESSURE AND RESOURCE DEPENDENCE

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## **ABSTRACT**

**Purpose:** This study investigates the transformation of business models in the maritime industry through the lens of Maritime Autonomous Surface Ships (MASS). It aims to explore how the interplay of institutional pressures and resource dependence influences firms' innovation orientation and acceptance of autonomous technologies, framing MASS as a niche innovation reshaping the maritime logistics ecosystem.

**Design/methodology/approach:** Grounded in Institutional Theory and Resource Dependence Theory, this study conceptualizes the transition toward MASS as a function of both institutional and resource-driven dynamics. Data were collected from senior executives in Taiwan's maritime logistics sector. Confirmatory Factor Analysis (CFA) and Structural Equation Modeling (SEM) were employed to empirically validate the proposed theoretical framework.

**Findings:** The results show that institutional pressures—such as regulatory mandates, safety compliance, and stakeholder expectations—positively influence both firms' resource configurations and their orientation toward innovation. These pressures are also directly associated with more favorable attitudes toward MASS adoption. Conversely, while resource dependence promotes innovation, it also contributes to negative attitudes toward MASS, particularly among small and medium-sized enterprises. Niche innovations, including digitalization, automation, and blockchain, were found to enhance support for autonomous shipping.

**Practical implications (if applicable):** The findings provide actionable insights for maritime policymakers, technology developers, and shipping firms. Understanding how institutional and resource-related factors jointly shape innovation adoption can guide more effective policy designs and strategic investments that facilitate a just transition toward autonomous shipping, particularly for resource-constrained firms.

**Originality/value:** This study contributes to the growing literature on business model transformation and maritime innovation by conceptualizing MASS as a niche innovation influenced by institutional-resource tensions. It offers novel empirical evidence on how such tensions shape attitudes toward autonomy, advancing theoretical understanding of adaptive capacity and innovation diffusion in the maritime sector.

**Keywords:** Institutional pressure, Resource dependence, Niche innovations, Attitudes toward the Maritime Autonomous Surface Ships (MASS)

## **Introduction**

The maritime industry is undergoing significant transformation due to technological advancements and the push for sustainable, efficient shipping. Maritime Autonomous Surface Ships (MASS) represent a key innovation in this shift. Human error, often linked to fatigue, causes most maritime accidents (Dominguez-Péry et al., 2021). Using remote control and autonomous navigation can reduce these errors and lower risks to ships, crews, and cargo. MASS can also reduce piracy threats, as controlling autonomous systems onboard is difficult, and uncrewed vessels eliminate hostage risks (Olapoju, 2023). Additionally, MASS remove the need for crew accommodations, cutting construction and operational costs while reducing fuel use (Dantas and Theotokatos, 2023).

The International Maritime Organization (IMO) first introduced the term MASS during the 99th Maritime Safety Committee session in 2018. Semiconductor and ICT innovations have increased interest in autonomous ships, with companies like Rolls-Royce investing in uncrewed vessel development (Askari and Hossain, 2022). MASS can operate at different autonomy levels and can improve safety, reduce costs, and minimize environmental impacts (Wiróbal et al., 2017). The IMO categorizes MASS into four levels of autonomy: MASS-1 involves onboard crew with automated decision support; MASS-2 involves remote control with crew onboard; MASS-3 involves remote control without crew; and MASS-4 includes fully autonomous ships making decisions without human intervention (Sharma and Kim, 2022). Despite growing

interest, there is limited empirical research on shipping operators' attitudes toward MASS. This study aims to fill this gap by examining these attitudes within the industry.

Institutional pressures shape how industry operators adopt and implement innovations in shipping (Kuo et al., 2022). Institutional theory suggests that norms, values, and expectations in the environment influence organizations through regulations, industry standards, and stakeholder demands (Fan et al., 2020; Murim, 2019). Resource dependence theory explains how organizations' reliance on critical resources affects their decisions and behavior. Shipping operators depend on capital, technology, skilled labor, and partnerships to stay competitive (Panayides and Wiedmer, 2011). This dependence can either encourage or limit technology adoption (Adner and Kapoor, 2010).

Niche innovations, supported by advanced data analytics and ICT systems, drive digitalization and automation in shipping (Kim et al., 2021; Johansson et al., 2021). Technologies like intelligent containers (Lang and Jedermann, 2016) and blockchain (Yang, 2019; Fonseca et al., 2021) enhance safety, environmental performance, and efficiency, demonstrating the role of niche innovations in transforming maritime logistics.

Current studies often use the Technology Acceptance Model (TAM) to explore technology adoption but fail to capture the layered, systemic transitions needed for MASS. This study addresses this gap by conceptualizing MASS adoption as a multi-layered transition shaped by institutional pressures and moderated by resource constraints, providing a clearer view of adoption pathways and barriers. This study is guided by two research questions:

RQ1: How do shipping operators perceive institutional pressure, resource dependence, niche innovation, and attitudes toward MASS?

RQ2: What are the direct, indirect, and total effects of institutional pressure and resource dependence on niche innovation and attitudes toward MASS?

By exploring these questions, this study aims to help policymakers, industry leaders, and technology developers understand the factors shaping MASS adoption. It identifies barriers and drivers of niche innovations, providing insights for creating supportive environments for MASS in shipping. The study builds a research framework (Figure 1) showing the impact of institutional pressure, resource dependence, and niche innovation on attitudes toward MASS. Section 2 covers the theoretical background and hypotheses, Section 3 describes the methodology, and Section 4 presents the analysis results. The study concludes by discussing the findings and their implications for maritime transport while outlining limitations and future research directions.

### **Literature review and research hypotheses**

While prior research has examined the technical feasibility, legal frameworks, and socio-technical challenges of Maritime Autonomous Surface Ships (MASS) ( Ringbom, 2019; Ghaderi, 2019; Kim and Schröder-Hinrichs, 2021), relatively little attention has been devoted to the organizational decision-making processes underpinning their adoption—especially through the dual lenses of institutional theory and resource dependence. Existing studies typically treat institutional pressures (e.g., regulatory compliance, normative expectations) as unidirectional drivers of innovation (Fenton and Chapsos, 2023; Liu et al., 2022), and rarely consider how these external mandates interact with firms' internal resource constraints—such as limited capital, technological readiness, or human capacity—to influence strategic attitudes. Likewise, resource dependence research in the maritime context tends to emphasize operational vulnerabilities or outsourcing decisions (Pfeffer and Salancik, 1978; Biermann and Harsch, 2017), without integrating how these dependencies might responses to institutional pressure in the face of disruptive innovation. This creates a critical blind spot in understanding MASS adoption as a strategic transformation rather than a merely technical or regulatory issue.

## **Institutional Theory and Resource Dependence Theory**

Institutional theory provides a powerful lens to examine how organizations respond to external pressures and conform to societal expectations to gain legitimacy and ensure survival (DiMaggio and Powell, 1983; Scott, 2008). It posits that institutional environments—comprising regulatory, normative, and cognitive structures—influence organizational behavior by prescribing what is deemed acceptable or rational. In the maritime sector, these institutional pressures manifest through international regulations (e.g., IMO standards), national policies promoting digital transformation, and stakeholder demands for safety, transparency, and environmental performance (Tijan et al., 2021; Ringbom, 2019). Organizations subject to such pressures may align their strategies and adopt emerging technologies, such as Maritime Autonomous Surface Ships (MASS), not solely for operational efficiency but to enhance their legitimacy and secure continued stakeholder support (Suchman, 1995). Complementing this view, Resource Dependence Theory (RDT) emphasizes that organizations are embedded in networks of interdependencies and must manage their access to critical external resources—such as financial capital, technical knowledge, skilled labor, and regulatory approval—to ensure operational continuity and strategic flexibility (Pfeffer and Salancik, 1978). In the context of MASS adoption, firms face significant resource-related challenges, including high technological entry barriers, human capital shortages, cybersecurity concerns, and port infrastructure readiness (Aslam et al., 2020; Tusher et al., 2022). These dependencies constrain the decision-making autonomy of maritime firms and shape their strategic choices concerning technological innovation. Unlike prior studies that treat MASS adoption as technology acceptance, this study conceptualizes it as a systemic transition requiring orchestration of multiple niche innovations under institutional-resource tensions. Organizations with greater absorptive capacity and collaborative ties with technology providers may be better positioned to overcome these constraints (Cohen and Levinthal, 1990; Ghaderi, 2018), whereas firms with limited resources may exhibit resistance or delay adoption due to perceived risks and capability gaps (Oliver, 1991; Biermann and Harsch, 2017). This study conceptualizes the interaction between institutional pressure and resource dependence as a dynamic tension that significantly affects organizational attitudes toward niche innovations like MASS. While institutional forces may compel change, resource constraints can simultaneously inhibit or delay transformation, creating a complex adaptive landscape for maritime logistics actors navigating the shift to autonomy.

## **The Multi-Level Perspective (MLP)**

The Multi-Level Perspective (MLP), initially conceptualized by Geels (2002, 2004) and later refined in Geels (2014), provides a prominent theoretical lens to analyze socio-technical transitions. It conceptualizes change processes in complex systems as interactions across three analytical levels: niches, socio-technical regimes, and the socio-technical landscape. The framework has been extensively applied to study technological innovation in sectors such as energy, mobility, and shipping, especially in the context of sustainability transitions (Markard et al., 2012). At the core of MLP is the recognition that radical innovations, such as Maritime Autonomous Surface Ships (MASS), typically emerge in niches—protected environments that shield innovations from prevailing market selection pressures (Schot and Geels, 2008). These niches serve as experimental spaces where novel technologies, business models, and institutional practices can evolve and mature. In contrast, socio-technical regimes represent the dominant, stable configurations of technologies, user practices, regulations, infrastructures, and incumbent actors that sustain the current system (Geels, 2004). Regimes exhibit strong path dependencies and structural inertia, making them resistant to change. The landscape refers to the broader macro-level context, encompassing slow-changing external factors such as demographic trends, geopolitical shifts, environmental concerns, or supranational policy agendas (e.g., the IMO's decarbonization strategy or the European Green Deal). Changes at this level can exert pressure on the regime, creating windows of opportunity for niche innovations to break through (Geels, 2011). MLP conceptualizes transitions as non-linear, multi-dimensional, and co-evolutionary. A transition occurs when developments at the niche level (e.g., technological advancements in autonomy and digitalization) align with pressures at the landscape level (e.g., climate imperatives, cybersecurity concerns) and destabilize the existing regime (e.g., conventional crew-based shipping), thereby allowing niche innovations to scale and potentially redefine the dominant system (Geels and Schot, 2007). However, while MLP emphasizes systemic alignment and institutional co-evolution, it tends to under-

specify the firm-level constraints that affect innovation scaling—such as resource dependence, strategic ambiguity, and organizational inertia. Recent studies argue for complementing MLP with meso-level theories like Resource Dependence Theory (Pfeffer and Salancik, 1978) or Dynamic Capabilities Theory (Teece et al., 1997) to better understand the microfoundations of strategic decision-making under institutional pressure (Bergek et al., 2015; Köhler et al., 2019). In the context of MASS, the MLP provides a powerful macro-level explanation for the potential transition toward autonomous shipping. Yet, to capture the nuanced dynamics of business model transformation—particularly the oscillation of niche innovation between institutional pressure and resource dependence—it is necessary to integrate MLP with theories that foreground inter-organizational dependencies, resource asymmetries, and technological uncertainty.

### **The relationship between institutional pressure (IP), resource dependence (RD), niche innovation, and attitude toward MASS**

In this study, institutional pressure (IP) refers to the influence of regulations, government policies, industry standards, and customer expectations on organizational practices (Zhu and Sarkis, 2007; Yang, 2018). Resource dependence (RD) means organizations rely on external resources for survival and success (Yuen et al., 2017; Parvainen et al., 2018). Maritime shipping relies on customers and strategic partners, creating dependencies that require collaboration, resource sharing, and strong cybersecurity. The sector faces strict regulations from bodies like the International Maritime Organization (IMO) and national authorities. These rules set operational, safety, and environmental standards (Van Leeuwen, 2015). For example, IMO's greenhouse gas (GHG) targets push shipping lines to lower emissions by using cleaner fuels like LNG and adopting technologies such as scrubbers and optimized hull designs. These efforts create interdependencies with fuel suppliers and port operators who provide the needed infrastructure.

Downstream, companies like IKEA and Walmart set sustainability goals, requiring logistics partners to use greener transport options. This leads to closer collaboration and joint investment in green technologies, showing how institutional pressures drive supply chain cooperation. Compliance with regulations forces maritime firms to adapt operations by investing in new technologies, enhancing cybersecurity, and improving risk management (Lu et al., 2019; Kuo et al., 2022). To comply, firms must secure the necessary technologies and skilled personnel, increasing their dependence on external resources (Ichimura et al., 2022). Industry standards also exert institutional pressure. Aligning with norms set by bodies like the International Association of Classification Societies (IACS), DNV GL, or Bureau Veritas requires investments in monitoring, cybersecurity, and risk management technologies (Vajjar et al., 2018; Venkatesh and Bala, 2012). This alignment increases reliance on partners and suppliers to meet these standards.

Customer expectations further contribute to institutional pressure. Customers demand reliability, high service quality, and sustainable practices, prompting maritime firms to adopt advanced technologies and improve efficiency (Vajjar et al., 2018.) Meeting these demands requires collaboration with partners, increasing resource dependence. Technological advancements and shifting market trends continuously pressure maritime firms to adapt. This requires investments in technology, cybersecurity, and risk management to stay competitive (Mizrak, 2023). As firms adopt new systems, they rely on technology providers, cybersecurity experts, and partners, heightening resource dependence (Panayides and Wriedmer, 2011; Liu et al., 2023). In summary, institutional pressure drives resource dependence in maritime logistics. Regulations, industry standards, customer demands, and technology trends compel firms to secure external resources to remain operational and competitive. Based on this, the study proposes:

**H1. Institutional pressure is positively associated with resource dependence in maritime logistics.**

Regulatory bodies impose laws and standards that organizations must follow. Failure to comply can result in legal penalties, fines, and reputational damage (Shimshack and Ward, 2005). Faced with regulatory pressure, organizations often turn to niche innovations to ensure compliance. For instance, introducing stringent environmental regulations drives the development and adoption of green technologies (Cai et al., 2020), such as intelligent container technology to monitor and reduce emissions or automation and robotics to improve operational efficiency and reduce waste (Jin et al., 2021). For example, the International Maritime Organization's (IMO) regulations on sulfur emissions have led shipping companies to adopt technologies like scrubbers and alternative fuels (Van et al., 2019). Normative pressure arises from the

expectations of industry standards, best practices, and ethical norms. Organizations feel compelled to adhere to these standards to maintain legitimacy and reputation. To align with industry norms and expectations, organizations adopt niche innovations that signify adherence to high standards (Geels, 2004). For example, the push for sustainable practices within industries has led to adopting blockchain technology to enhance transparency and traceability in supply chains (Centobelli et al., 2022). Cognitive pressure stems from shared beliefs, values, and knowledge within an industry. It shapes how organizations perceive and respond to their environment. Organizations innovate to align with the prevailing cognitive frameworks (Geels, 2014). For example, believing in the importance of digital transformation leads companies to invest in advanced data analysis applications and automation technologies to stay competitive (Kraus et al., 2021). Competitive pressure forces organizations to innovate and maintain a competitive edge. This pressure often results in adopting niche innovations that provide unique capabilities or efficiencies (Hojnik and Ruzzier, 2016). Organizations invest in niche innovations such as automation and robotics for improved productivity or blockchain technology for enhanced security and transaction efficiency to outperform competitors (Alhal, 2023). In conclusion, institutional pressures create an environment where niche innovations are necessary and strategically advantageous for organizations. By responding to these pressures through innovation, organizations can ensure compliance, enhance their reputation, improve efficiency, and maintain competitiveness in their respective industries (Colwell and Joshi, 2013). Consequently, the study hypothesizes:

**H2. Institutional pressure is positively associated with niche innovation in maritime logistics.**

Institutional theory asserts that organizations respond to external pressures—regulatory, normative, and mimetic—in order to secure legitimacy, ensure survival, and align with socially accepted practices (DiMaggio and Powell, 1983; Scott, 2013). In the maritime sector, institutional pressures are increasingly shaping organizational attitudes toward Maritime Autonomous Surface Ships (MASS), particularly in response to evolving governance frameworks and environmental mandates. Regulatory pressures from the International Maritime Organization's (IMO) GHG strategy and MASS scoping exercise compel firms to re-evaluate the technical, safety, and sustainability implications of automation and autonomy (Liu et al., 2022; Fenton and Chapsos, 2023). Normative expectations issued by classification societies (e.g., DNV-CG-0294) and the alignment with emergent global operational standards reinforce the legitimacy of MASS as a strategic innovation (Tsvetkova et al., 2021). Additionally, mimetic pressures—exemplified by early adopters such as the *Yara Birkeland*—signal symbolic compliance and market relevance, thereby intensifying peer-driven conformity (Fonseca et al., 2021; Kim and Schröder-Hinrichs, 2021).

However, institutional pressures do not always result in straightforward adoption. As Suchman (1995) argues, legitimacy is a socially constructed perception of desirability within a system of shared norms. While conformity to institutional mandates may enhance regulatory or normative legitimacy, it also introduces operational uncertainties and cost burdens, especially in technologically immature domains such as MASS. This legitimacy–uncertainty tradeoff becomes particularly salient when regulatory expectations outpace firms' absorptive capacity or infrastructural readiness (Tijan et al., 2021). Consequently, institutional pressure may simultaneously act as a catalyst and constraint: it legitimizes MASS adoption as a future-oriented strategy to reduce labor costs, enhance navigational safety, and satisfy sustainability goals (Chaal et al., 2023), but may also generate risk aversion and ambivalent attitudes among firms with constrained capabilities (Munim and Haralambides, 2022). Therefore, institutional influence operates through both coercive and cognitive channels, shaping organizational orientation toward MASS not only as a compliance necessity, but also as a competitive imperative subject to perceived feasibility and risk. As a result, the study postulates:

**H3. Institutional pressure is positively associated with attitudes toward Maritime Autonomous Surface Ships (MASS) in maritime logistics.**

Institutional pressures, including regulatory mandates, industry norms, and stakeholder expectations, are conceptualized as landscape and regime pressures within the MLP framework. These pressures drive firms to increase resource dependence (H1), pursue niche innovations (H2), and form favorable attitudes toward MASS adoption (H3), aligning systemic pressures with organizational response mechanisms.

**The relationship between resource dependence, niche innovation, and attitude toward MASS**

In environments characterized by uncertainty and resource scarcity, organizations must navigate challenges related to resource availability. Organizations form relationships and cultivate interdependence with other firms to address these challenges and meet internal resource needs. This approach underscores the critical role of partnerships in managing resource dependence effectively (Biermann and Harsch, 2017). Resource Dependence Theory asserts that organizations are not self-sufficient and must secure resources from their environment to thrive. Managers, therefore, engage in strategies to manage external dependencies with two main objectives: ensuring the organization secures sufficient resources to maintain market presence and enhancing the organization's autonomy by minimizing external constraints (Biermann and Harsch, 2017). This dependency influences organizational behavior and strategy, ensuring access to essential resources such as raw materials, information, technology, human capital, and financial assets (Antony et al., 2023). These dependencies shape organizational strategies and innovations (Connelly et al., 2013). Shipping companies are significantly dependent on fossil fuels, making them vulnerable to price volatility and stringent carbon emissions regulations, which expose them to operational risks. Consequently, firms are driven to adopt innovative strategies, such as transitioning to alternative fuels like LNG, biofuels, or hydrogen and implementing energy-efficient technologies. For instance, CMA CGM's introduction of LNG-powered vessels exemplifies niche innovation stemming from resource dependence. Furthermore, reliance on limited port infrastructure creates supply chain bottlenecks, prompting logistics optimisation and digitalisation innovations. Maersk's involvement in blockchain-based initiatives aims to digitise bills of lading, enhancing transparency and operational efficiency across the industry.

Fluctuations in resource availability, quality, and cost necessitate innovative approaches to ensure stable resource supply (Mukherjee, 2023). For instance, organisations rely on timely and accurate information to make strategic decisions, leading to advancements in data analytics, big data, machine learning, and artificial intelligence to enhance decision-making (Biharadiya, 2023). Additionally, niche innovations like automation and robotics increase operational efficiency, reduce labour costs, and mitigate risks (Mindell and Reynolds, 2023). Intelligent container technology uses IoT sensors to monitor transit goods, ensure optimal conditions, reduce manual tracking, minimise losses, and ensure regulatory compliance (Chhikara et al., 2020). Technological reliance drives innovation in specialised areas like predictive analytics, AI-based ship routing, and autonomous vessels in a globalised and interconnected shipping network. Rolls-Royce and Wärtsilä's autonomous ships exemplify niche innovation addressing human dependency and operational inefficiencies, enhancing safety and route efficiency through advanced artificial intelligence and sensor technologies. Therefore, dependency on external resources drives the pursuit of such innovations to provide alternative or more efficient resources. These innovations are vital for managing dependencies, mitigating risks, and maintaining competitiveness in a dynamic, resource-constrained environment (Adner and Kapoor, 2010). The intrinsic link between resource dependence and niche innovation is evidenced by the causative relationship where the dependency on external resources necessitates innovative solutions (Jaja et al., 2017; Akram and Abrar Ul Haq, 2022). Thus, the study proposes:

**H4. Resource dependency is positively associated with niche innovation in maritime logistics.**

Resource Dependence Theory (RDT) (Pfeffer and Salancik, 1978) explains that organizations rely on external environments for critical resources, including capital, labor, infrastructure, and technology. This dependency shapes their strategic choices and innovation capacity. In the case of Maritime Autonomous Surface Ships (MASS), moving toward autonomy requires firms to adopt advanced systems such as artificial intelligence (AI), secure communication networks, sensor-based navigation, and MASS-compatible port infrastructure (Ahmed et al., 2024; Aslam et al., 2020). Firms that rely on legacy systems like manned vessels and conventional port operations often face a mismatch between their current resources and the needs of MASS. This mismatch creates perceived threats to existing relationships, routines, and human skills that have ensured operational stability (Schuster and Holbrügge, 2014; Biermann and Harsch, 2017). As a result, firms with limited resources may resist adopting MASS, not only because of financial constraints but also due to a lack of absorptive capacity to adopt radical innovations (Cohen and Levinthal, 1990). The introduction of MASS affects the broader maritime logistics ecosystem. Deploying autonomous vessels requires coordination among technology developers, shipyards, shipowners, agents, forwarders, and inland logistics providers. It also demands high initial investments for technology upgrades, fleet retrofits, port control centers, and workforce upskilling (Tsvetkova and Hellström, 2022). Regulatory harmonization under

international frameworks like SOLAS, COLREGs, and STCW further complicates the transition (Ringbom, 2019; Ahmed et al., 2024).

MASS implementation involves multiple institutional actors, including classification societies, insurers, port authorities, customs agencies, and financial institutions. Their hesitancy, driven by regulatory uncertainty, liability concerns, and technology reliability issues, can delay integration (Soyer and Tetterborn, 2019; Dantas and Theodorakos, 2023). Autonomous systems must demonstrate resilience under various conditions, including system failures and cybersecurity threats (Aalam et al., 2020; Tusher et al., 2022). Until certified and accepted, stakeholders may hesitate to invest in or support MASS infrastructure. MASS also changes maritime labor practices, shifting from crew-based operations to AI-driven systems. This shift requires new skills and closer collaboration with technology providers (Ghaderi, 2019; Emad and Ghosh, 2023). For smaller firms, the decision to adopt MASS is challenging due to high upfront costs and uncertainty, despite promises of efficiency and safety gains (Munim, 2019; Kurt and Aymelek, 2022). These factors show that resource dependence can both enable and constrain MASS adoption. Firms with aligned resources may see MASS as an opportunity, while those lacking capacity may view it as disruptive, leading to resistance. Based on this understanding, this study proposes:

**H5. Resource dependency is negatively associated with attitudes toward MASS in maritime logistics.**

Resource dependence reflects the meso-level constraints that firms face when responding to external pressures, shaping their strategic behavior in technology transitions. It fosters niche innovation adoption (H4) while simultaneously generating cautious or negative attitudes toward MASS due to risk perceptions and legacy system sickness (H5).

#### **The relationship between niche innovation and attitude toward MASS**

Niche innovations, such as advanced data analysis applications (Kim and Schröder-Hinrichs, 2021), automation and robotics (Johansson et al., 2021), intelligent container technologies (Lang and Jedermann, 2016), and blockchain technology (Fonseca et al., 2021), play a crucial role in shaping attitudes toward Maritime Autonomous Surface Ships (MASS). These innovations address vital challenges and enhance the overall feasibility, environmental impact, safety, security, and efficiency of autonomous shipping (Chaal et al., 2023). Advanced data analysis tools, such as big data analytics and machine learning, offer maritime operators essential insights into operational performance, predictive maintenance, and route optimization (Munim et al., 2020). Through these technologies, Maritime Autonomous Surface Ships (MASS) can make data-driven, real-time decisions, significantly improving operational efficiency and reliability. These analytical tools enable MASS to optimize fuel usage, forecast weather conditions, and predict maintenance requirements, ultimately lowering operational costs and minimizing environmental impacts (Kurt and Aymelek, 2024; Zis et al., 2023). Such advancements contribute to growing confidence in the technical viability of MASS.

Autonomous navigation systems, robotic maintenance, and automated cargo handling demonstrate that MASS can operate independently of human intervention (Poomikoo and Øvergaard, 2022). The successful implementation of these technologies proves the technical feasibility of autonomous ships, encouraging a positive attitude towards MASS. Intelligent container technology, which uses IoT sensors and real-time tracking, allows for continuous monitoring of cargo conditions. This capability ensures that autonomous ships maintain optimal conditions for sensitive cargo, reducing spoilage and loss (Mufuzuri et al., 2020). The practical benefits of improved cargo management support a positive attitude towards the practicality and effectiveness of MASS. Blockchain technology guarantees secure, transparent, and unalterable records of transactions and communications throughout the maritime ecosystem, streamlining documentation processes, reducing administrative burdens, and ensuring precise record-keeping (Yang, 2019). The ability to prevent fraud and ensure data integrity through blockchain fosters a positive attitude toward the reliability and security of autonomous ships (Munim and Haralambides, 2022). This streamlining of operations demonstrates the operational benefits of MASS, leading to a more favorable perception of their adoption. In conclusion, advancements in data analysis, automation, intelligent container technology, and blockchain create a foundation that enhances autonomous ships' feasibility, efficiency, safety, and environmental impact. These tangible benefits foster a positive attitude towards MASS, encouraging their adoption and integration into the maritime industry. Thus, the proposed hypothesis is:

H6. Niche innovation is positively associated with the attitude to MASS in maritime logistics.

Niche innovations, including AI-enabled navigation, blockchain, and automation, act as protected experiments within the MLP structure, allowing radical technologies to evolve and mature while insulated from immediate regime pressures. Niche innovations as protected experiments in MLP, enabling MASS systemic adoption. Therefore, this study examines how niche innovations positively influence organizational attitudes, enabling MASS adoption as part of a systemic business model transition.

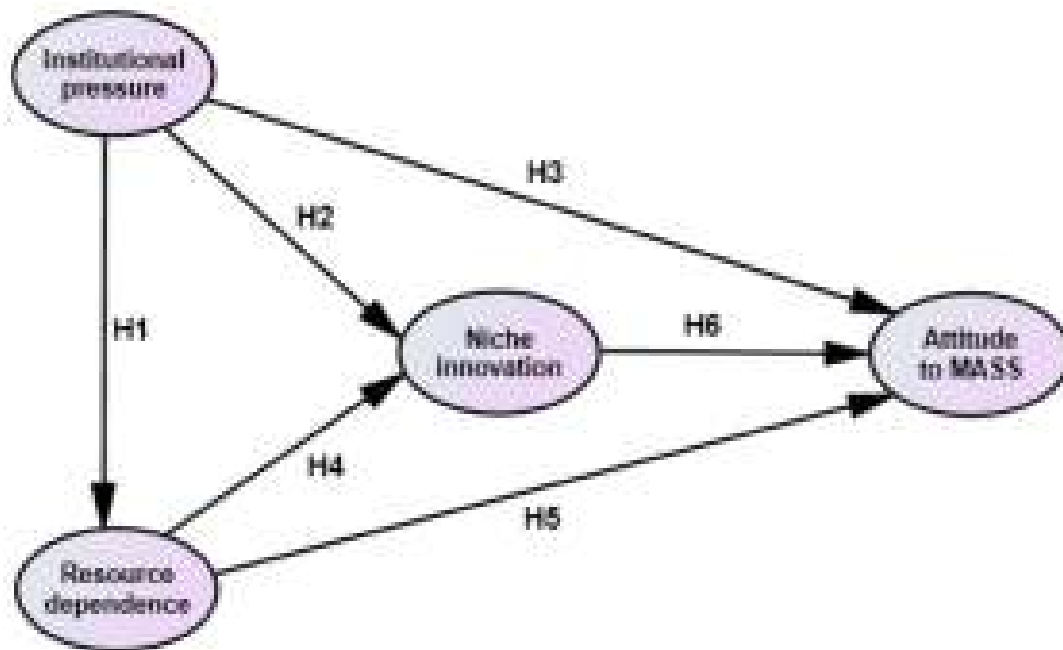


Figure 1: Conceptual research model.

## Methodology

### Sampling method

This study empirically investigates the influence of institutional pressure and resource dependence on niche innovation and attitudes toward MASS (Maritime Autonomous Surface Ships) within the maritime transport domain. To this end, the research enlisted participants primarily from the National Association of Chinese Shipowners (NACS) and the International Ocean Freight Forwarders and Logistics Association (IOFFLA). The study distributed return envelopes to 511 individuals in 2024. In the initial round of data collection, 108 responses were obtained. A follow-up survey was administered one month later, yielding 55 responses. In total, 163 valid responses were collected, corresponding to an overall response rate of 31.9%. A t-test was conducted as recommended by Armstrong and Overton (1977) to assess nonresponse bias. The dataset was divided into two waves: early respondents ( $n = 108$ ) and late respondents ( $n = 55$ ). Since no statistically significant differences were observed between the two groups across the measured dimensions at the 5% significance level, it can be concluded that nonresponse bias did not pose a concern in this study.

## Measures developing

Table 1: Constructs' operational definition.

Constructs	Operational definitions	Key references
Institutional pressure	Maritime shipping operations must comply with regulatory requirements, governmental policies, and normative industry standards. Additionally, they should align with customer-endorsed strategies and practices while continually adapting to dynamic market conditions and evolving technological advancements.	Zhu and Sarkis (2007); Clemens and Douglas (2005); Yang (2018)
Resource dependence	Maritime shipping operations are deeply intertwined with the global market, requiring substantial resource dependence on customers and strategic partners and swift responses to their evolving needs. High levels of collaboration, resource sharing, cybersecurity, and risk management are crucial for maintaining the integrity and resilience of these operations.	Yuen et al. (2017); Parvainen et al. (2018); Parola and Lam (2018)
Niche innovation	A high-level data analysis decision system and increased digitalization and automation are progressively integrated into maritime industry operations. Additionally, intelligent container technology and blockchain adoption are gaining traction within the industry.	Wiśnicki et al. (2021); Stalmokaitė et al. (2023); Stalmokaitė and Yliskylä-Peuralahti (2019)
Attitude to MASS	MASS is technically viable and is expected to mitigate the environmental footprint of the shipping sector while enhancing vessel and cargo safety and security measures. It will gradually replace traditional merchant ships.	Kim and Schröder-Hinrichs (2021); Gu et al. (2021); Wróbel et al. (2023); Li and Yuen (2022)

To ensure the trustworthiness of this study, the metrics were developed by synthesizing knowledge gleaned from prior scholarly research and expert viewpoints within the maritime transport domain, as elaborated in Table 1. Consequently, the facets related to institutional pressure, resource dependence, niche innovation, and attitudes toward Maritime Autonomous Surface Ships (MASS) underwent refinement. Additionally, a five-point Likert scale was incorporated into the questionnaire to assess the level of agreement among participants regarding each dimension, with the scale ranging from 1, representing strong disagreement, to 5, denoting strong agreement.

### Data analysis methods

In the current investigation, Confirmatory Factor Analysis (CFA) was utilized to authenticate the research framework, which comprises four fundamental dimensions: institutional pressure, resource dependence, niche innovation, and attitudes toward Maritime Autonomous Surface Ships (MASS), as delineated by antecedent research. Subsequently, Structural Equation Modeling (SEM) was employed to scrutinize the six posited research hypotheses, followed by an evaluation of direct, indirect, and total effects. These analytical procedures were executed using specialized statistical software, namely AMOS 18.0 and SPSS 18.

## **Analysis and results**

### **Respondent profile**

Table 2 presents a breakdown of the demographic characteristics of the participants in the survey, offering a statistical synopsis of their profiles. An overwhelming majority, 81%, of the survey respondents hold positions involving decision-making or managerial responsibilities within their respective organizations, occupying roles ranging from assistant director level to higher. This suggests that the demographic composition of the survey sample indicates seasoned professionals and can offer insights into the actual experiences and perspectives of company leadership concerning institutional pressure, resource dependence, niche innovation, and attitude toward Maritime Autonomous Surface Ships (MASS). Furthermore, approximately 74.2% of the respondents boast over five years of industry experience in maritime transportation. Such extensive tenure within the industry provides a solid foundation for comprehending the institutional pressure, resource dependence, niche innovation, and attitude toward Maritime Autonomous Surface Ships (MASS) prevalent in recent years.

Table 2: Respondent demographics (n=163).

		Rate of occurrence	percent
Professional title	The vice president or above	51	31.3
	Manager/Assistant manager	52	31.9
	Director/Assistant director	29	17.8
	Sales representative	31	19.0
Department	Operations	20	12.3
	Management	71	43.6
	Finance	11	6.7
	Sales	61	37.4
Seniority	Under 5 years	42	25.8
	6-10 years	29	17.8
	11-15 years	24	14.7
	16-20 years	15	9.2
	Over 20 years	53	32.5
Firm type	Ocean transport company	45	27.6
	Shipping agency	43	26.4
	Ocean freight forwarder	75	46.0
Ownership structure	Local firm	136	83.4
	Foreign-local firm	14	8.6
	Foreign-owned firm	13	8.0
The company's operational longevity	Less than 10 years	29	17.8
	11-20 years	30	18.4

	21–30 years	43	26.4
	More than 30 years	61	37.4
Employees count	Under 100 people	130	79.8
	101 to 300 people	15	9.2
	Over 300 people	18	11.0

### Instrument's reliability and validity

This study used Confirmatory Factor Analysis (CFA) to test the alignment between latent constructs and their measured items within the proposed framework. Table 3 presents the model's fit, validity, and reliability. Key fit indicators confirm a satisfactory model. The chi-square to degrees of freedom ratio is 1.641, indicating an acceptable fit. The Goodness of Fit Index (GFI) is 0.898, while the Comparative Fit Index (CFI) reaches 0.963, showing improvement over a null model. The Normed Fit Index (NFI) is 0.903, also indicating good fit. The Root Mean Square Residual (RMR) is 0.027, reflecting low residuals. The Root Mean Square Error of Approximation (RMSEA) is 0.058, indicating a good match while considering model complexity. Together, these results support the model's adequacy, consistent with Byrne (2013).

Table 3. Findings from the CFA (confirmatory factor analysis)

Latent variables	Unstandardized factor loading	Completely standardized factor loading	Standard error	Critical Ratio <sup>a</sup>
<b>{1: Institutional pressure (IP)}</b>				
IP1	1.000	0.764	— <sup>b</sup>	—
IP2	0.915	0.765	0.095	9.637***
IP3	0.927	0.778	0.095	9.805***
IP4	0.924	0.787	0.093	9.927***
<b>{2: Resource dependence (RD)}</b>				
RD1	1.000	0.727	— <sup>b</sup>	—
RD2	1.015	0.783	0.110	9.213***
RD3	0.909	0.732	0.105	8.657***
RD4	0.960	0.761	0.107	8.981***
<b>{3: Niche innovation (NI)}</b>				
NI1	1.000	0.781	— <sup>b</sup>	—
NI2	1.175	0.738	0.123	9.571***
NI3	1.031	0.787	0.100	10.312***
NI4	0.922	0.785	0.090	10.272***
<b>{4: Attitude to MASS (AT)}</b>				
AT1	1.000	0.756	— <sup>b</sup>	—

AT2	1.011	0.825	0.095	10.605***
AT3	1.157	0.856	0.105	11.014***
AT4	1.015	0.836	0.094	10.753***

Note: a. S.E. stands for the estimate of the standard error of the covariance.

b. C.R. represents the critical ratio obtained by dividing the covariance estimate by its standard error. \*\*\* stands for the correlation is significant at the 0.001 level.

c. Refers to a parameter fixed at 1.0 in the original solution.

In this study, convergent validity was used to assess the fidelity of the measurement tool in capturing the intended construct. This entailed scrutinizing whether the relevant items adequately reflect the latent variables. The examination of Average Variance Extracted (AVE) values served as a gauge for the study's convergent validity, aligning with the criteria established by Fornell and Larcker in 1981, stipulating that AVE values should surpass 0.5 to ensure satisfactory convergent validity. Consequently, the measurement instrument represents the theoretical construct it endeavors to measure accurately. The empirical data presented in Table 4 corroborate the assertion that the instrument meets the accepted standards of convergent validity. In contrast, discriminant validity is a pivotal tool for assessing whether two latent variables exhibit minimal correlation. Analyzing a correlation matrix is indispensable for evaluating this aspect of validity. Table 4 illustrates this matrix, with squared correlations between latent variables situated off the diagonal and the AVE depicted on the diagonal. Adequate discriminant validity necessitates that the AVE values represented by the diagonal elements of the matrix exceed the squared correlation values present in the off-diagonal components of each row and column. This criterion is supported by the research findings of Segars and Grover (1998). The values presented in Table 4 affirm that the discriminant validity of the study falls within acceptable parameters.

Another indication of the internal quality of a measurement model can be achieved by a close examination of the standardized residuals and the modification indices (Bagozzi and Yi, 1988). The standardized residuals or so-called normalized residuals provided by the AMOS program represent the differences between the observed correlation/covariance and the estimated correlation/covariance matrix. Standardized residuals with values larger than 1.96 in absolute terms are considered statistically significant at the 0.05 level, indicating that substantial variances remain unexplained and that a specification error is likely (Hair et al., 2021). Accordingly, pairs of measures showing standardized residuals greater than 1.96 indicate the area of misspecification. Results reveal that no standardized residual values exceeded 1.96 in absolute terms. This provided additional evidence of model fit and of no apparent misspecifications.

Table 4: AVE and squared correlations comparison.

Construct	IP	RD	NI	AT
IP	<b>0.598</b>			
RD	0.334	<b>0.564</b>		
NI	0.398	0.436	<b>0.598</b>	
AT	0.253	0.091	0.223	<b>0.671</b>

Note: AVEs are on the diagonal; square correlations are off-diagonal.

### Hypotheses testing

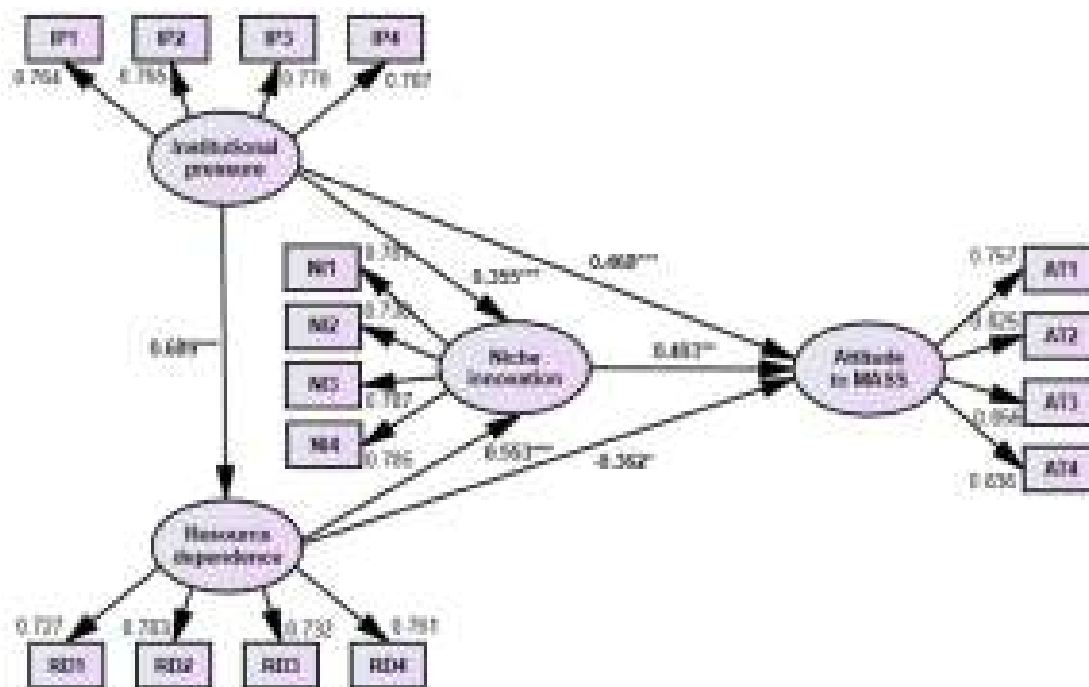
Utilizing the Structural Equation Modeling (SEM) methodology, this study concurrently investigated the interrelations among institutional pressure, resource dependence, niche innovation, and attitudes to MASS within the maritime logistics industry. As illustrated in Table 5 and Figure 2, the empirical results enabled a comprehensive examination of the proposed causal relationships among these variables. The findings strongly support Hypotheses 1, 2, 3, and 4, all statistically significant at the 0.001 level. Additionally,

Hypothesis 5 is supported at a significance level of 0.05. Hypothesis 6 also finds support, with statistical significance at the 0.01 level.

Table 5: SEM standardized outcomes for hypotheses

	Estimate ( $\beta$ )	P	Outcome
H1: Institutional pressure $\rightarrow$ Resource dependence	0.689 ( $\beta_1$ )	***	Supported
H2: Institutional pressure $\rightarrow$ Niche innovation	0.355 ( $\beta_2$ )	***	Supported
H3: Institutional pressure $\rightarrow$ Attitude to MASS	0.468 ( $\beta_3$ )	***	Supported
H4: Resource dependence $\rightarrow$ Niche innovation	0.553 ( $\beta_4$ )	***	Supported
H5: Resource dependence $\rightarrow$ Attitude to MASS	-0.362 ( $\beta_5$ )	*	Supported
H6: Niche innovation $\rightarrow$ Attitude to MASS	0.483 ( $\beta_6$ )	**	Supported

Note: \*\*\* significant at the 0.001 level; \*\* significant at the 0.01 level; \* significant at the 0.05 level



Fit indices:  $\chi^2/d.f. = 1.541$ ;  $p = 0.000$ ; GFI= 0.895; CFI= 0.963; NFI= 0.903; IFI= 0.964; RMSEA= 0.058; SRMR= 0.027

Note: \*\*\* significant at the 0.001 level; \*\* significant at the 0.01 level; \* significant at the 0.05 level

Figure 2: Structural equation model estimation.

Figure 2 employs structural equation modeling (SEM) to elucidate the relationships and their corresponding path coefficients, offering a comprehensive understanding of the interactions between these constructs. Hypothesis 1 (H1) results indicate a strongly positive relationship between the institutional pressure shipping operators perceive and their resource dependence, as evidenced by its coefficient. This suggests that institutional pressure positively correlates with resource dependence among shipping operators. Regarding Hypothesis 2 (H2), the findings reveal a significant positive relationship between institutional pressure and niche innovation. Institutional pressures such as regulatory requirements, industry norms and

standards, and customer expectations in the shipping industry promote niche innovative technologies and practices. The positive coefficient associated with Hypothesis 3 (H3) demonstrates that institutional pressure within the maritime industry significantly influences operators' attitudes toward Maritime Autonomous Surface Ships (MASS).

An essential point of discussion arises from the findings related to hypothesis H5, which reveals a negative correlation. This suggests that increased resource dependence is linked to a less favorable perception of Maritime Autonomous Surface Ships (MASS). This empirical result corroborates the research by Fonseca et al. (2021), which posits that maritime shipping operators exhibit limited interest in fully autonomous shipping. Instead, they prefer niche technologies that enhance ship intelligence and connectivity. This preference likely stems from the fact that maritime shipping operators, heavily dependent on global market resources and collaborative resources with supply chain partners, are apprehensive about the potential disruptions caused by fully autonomous ships. Such disruptions could compel them to deviate from their existing business model and necessitate a transition and integration into the new MASS business paradigm. Shipping operators may also be hesitant about MASS because they attach great importance to cybersecurity and risk management among supply chain partners. The study concludes that with MASS's emergence, shipping industry operators face a complex and contradictory situation. As previous research has shown, introducing MASS will require significant changes in the maritime shipping ecosystem, including new business models and roles among technology providers, shipyards, shipowners, and operators (Tsvetkova and Helleström, 2022).

While MASS shows promise, significant challenges remain. These include ensuring the safety and security of MASS operations, developing regulatory frameworks that can effectively govern MASS, and gaining stakeholder acceptance for the changes MASS will bring to the industry. The results suggest that the future of MASS lies in incremental progress and increased levels of niche innovation integrating virtual and physical rather than the immediate achievement of complete autonomy. The strong positive correlation observed with Hypothesis 6 (H6) indicates that as maritime operators' perception of niche innovation increases, so does their inclination towards favoring maritime autonomous surface ships (MASS). Implementing data analysis, automation, smart technologies, and blockchain innovations significantly enhances autonomous vessels' feasibility, efficiency, and attractiveness. Furthermore, each indicator (IP1-IP4, RD1-RD4, NI1-NI4, AT1-AT4) demonstrates a loading coefficient, illustrating the strength with which these indicators measure their respective latent constructs. The coefficients are all relatively high, ranging from 0.727 to 0.856, indicating strong correlations between the indicators and their constructs.

## **Conclusion and discussion**

### **Theoretical implications**

This study extends key literature streams at the intersection of institutional theory, resource dependence, and innovation adoption in the maritime sector. First, prior research has shown that institutional pressures, including regulatory, normative, and mimetic forces, shape technology adoption and innovation trajectories across industries (Huang and Huang, 2024; Tang et al., 2019). In maritime contexts, such pressures often originate from bodies like the IMO, classification societies like DNV, and evolving industry standards. These mechanisms influence the adoption of autonomous technologies, including MASS, by shaping organizational expectations of legitimacy and compliance (Li and Yuen, 2022). Second, institutional pressure does not only drive compliance. It can also increase resource interdependence among firms and their technology partners or supply chain stakeholders (Saeed et al., 2018; Zhu and Sarkis, 2007). This aligns with Resource Dependence Theory (Pfeffer and Salancik, 1978), which posits that environmental constraints and regulatory complexity drive firms to depend on external capabilities to meet compliance. For MASS, this includes reliance on advanced digital solutions, AI-enabled navigation, and cybersecure infrastructures (Ichimura et al., 2022). However, this reliance also raises concerns about data security, system resilience, and cyber risks, which are critical for business continuity and trust (Chang et al., 2021).

Third, the literature on organizational innovation adoption suggests that resource-sharing and inter-organizational collaboration can accelerate the diffusion of niche innovations in sectors with high entry barriers (Schuster and Hoffbrügge, 2014). In maritime logistics, such collaboration is essential due to the capital-intensive nature of retrofitting, system integration, and training for MASS. Yet, institutional mandates

often precede firms' internal absorptive capacities (Cohen and Levinthal, 1990). This study finds that resource dependence can foster niche innovations while simultaneously dampening positive attitudes toward MASS adoption. Firms with high external dependencies may perceive MASS as adding operational uncertainties that could destabilize supply chains. Legacy investments may further constrain flexibility, while concerns about technological uncertainty, cybersecurity, and liability may prompt caution. Limited absorptive capacity can hinder firms from using advanced knowledge required for MASS, fueling skepticism despite potential benefits. Thus, resource dependence can act as both a catalyst for incremental innovation and a constraint on disruptive adoption. Recognizing these dynamics enriches our theoretical understanding of resource dependence in socio-technical transitions and identifies practical barriers policymakers must address.

Fourth, while the Technology Acceptance Model (TAM) (Davis, 1989) has helped explain individual responses to single innovations, it does not capture the systemic nature of MASS transitions. MASS adoption involves multi-layered reconfigurations of business models and operational structures within evolving regulatory environments. It requires orchestrating multiple niche innovations like AI navigation, blockchain logistics, and automated port operations. By framing MASS as a system-level transformation, this study moves beyond TAM's individual focus. It shows how institutional pressures and resource dependencies shape maritime firms' strategic repositioning within a digitally enabled, decarbonizing landscape. Using the Multi-Level Perspective (MLP) (Geels, 2014), this study conceptualizes niche innovations as protected spaces where radical technologies can evolve. MASS becomes a locus of innovation at the intersection of digitalization, decarbonization, and automation, supporting systemic change when aligned with evolving institutional demands. This positions MASS adoption as a transition pathway, catalyzed by institutional strain, that destabilizes existing regimes while legitimizing investments in automation and AI navigation.

This study advances socio-technical transition research by integrating MLP with Resource Dependence Theory and Institutional Theory to explain MASS adoption. While MLP conceptualizes transitions across landscape, regime, and niche levels, it often lacks micro-level detail on organizational constraints (Bergek et al., 2018; Köhler et al., 2019). This study shows how institutional pressures filter through firm-specific dependencies like capital, technology readiness, and partnerships, influencing niche innovation adoption (Tijan et al., 2021). It demonstrates that institutional strain becomes an effective driver of systemic innovation only when mediated by firm-level capabilities, extending MLP's macro insights with micro-level depth for analyzing transitions in capital-intensive sectors (Markard et al., 2012). The findings suggest that niche innovations drive positive attitudes toward MASS when firms see them as aligned with long-term goals like sustainability and competitiveness. MASS becomes a platform to reconcile regulatory compliance with innovation, acting as a regime-shifting tool to navigate institutional turbulence. This contributes to transition literature by showing how institutional pressure functions not only as a coercive force but also as a catalyst for niche-driven business model reorientation in the maritime sector.

### **Practical implications**

The empirical findings in Figure 2 provide clear, actionable insights for maritime industry stakeholders seeking to navigate the transition toward Maritime Autonomous Surface Ships (MASS) under institutional and resource constraints. First, the strong positive influence of institutional pressure on resource dependence ( $\beta_1 = 0.689, p < 0.001$ ) highlights that regulatory bodies, classification societies, and industry standards play a decisive role in shaping the strategic environment for MASS adoption (Fenton and Chapsos, 2023; Liu et al., 2022). Maritime policymakers and regulators should recognize that stringent compliance expectations often increase firms' reliance on external technology providers, digital infrastructure, and specialized skills. To mitigate excessive dependency risks and facilitate smoother transitions, regulators could implement phased regulations, sandbox environments, and public-private innovation platforms (Tijan et al., 2021).

Second, the positive path from institutional pressure to niche innovation ( $\beta_2 = 0.355, p < 0.001$ ) suggests that institutional mandates catalyze experimentation with niche technologies, such as AI navigation, remote monitoring, and blockchain-supported operational management, within shipping firms (Geels, 2014; Tsvetkova and Hellström, 2022). Maritime leaders should leverage this alignment by proactively investing

in pilots and demonstrations of MASS technology, positioning compliance as an opportunity for competitive differentiation and service innovation (Murim and Haralambides, 2022). Third, niche innovation significantly enhances positive attitudes toward MASS ( $\beta_3 = 0.493$ ,  $p < 0.01$ ), indicating that the incremental integration of niche technologies is key to building organizational readiness for fully autonomous operations (Ringbom, 2019; Chaal et al., 2023). Shipping companies are advised to adopt stepwise integration strategies—such as incorporating semi-autonomous navigation or automated cargo handling systems—to gradually prepare their workforce, technical infrastructure, and operational routines for the broader implementation of MASS (Kim and Schröder-Hinrichs, 2021).

Fourth, the negative relationship between resource dependence and attitudes toward MASS ( $\beta_4 = -0.362$ ,  $p < 0.05$ ) reveals that firms with high external dependency may perceive MASS as a disruptive threat rather than an opportunity, driven by concerns over technological uncertainty, capability gaps, and potential loss of control (Cohen and Levinthal, 1990; Pfeffer and Salancik, 1978). To address this, maritime clusters and industry associations could facilitate resource pooling, shared training initiatives, and collaborative R&D, enabling smaller operators to overcome capability limitations and mitigate perceived risks associated with MASS adoption (Schröder-Hinrichs et al., 2019).

Finally, given the dual role of resource dependence, policymakers should consider subsidy programs, shared testing environments, and knowledge-sharing initiatives to mitigate firms' perceived risks while maintaining innovation incentives. Resource dependence can simultaneously drive firms to pursue niche innovations and create caution toward adopting disruptive technologies like MASS due to concerns about operational risks and technological uncertainties. By providing financial support mechanisms and collaborative testing frameworks, policymakers can reduce perceived barriers, enabling firms to engage in systemic transitions while safeguarding competitive positioning. Knowledge-sharing initiatives can further support capacity-building and reduce information asymmetries, allowing firms to better evaluate the risks and benefits of MASS adoption within a structured and supportive innovation ecosystem.

### **Limitations and future research suggestions**

This study offers new insights into how institutional pressure, resource dependence, and niche innovation shape attitudes toward Maritime Autonomous Surface Ships (MASS). However, several limitations create opportunities for future research. First, the study used a sample from maritime logistics operators in Taiwan. This limits the generalizability of the findings to other regions and institutional contexts (Tijan et al., 2021). Future studies should include global stakeholders such as shipyards, port operators, insurers, classification societies, cargo owners, and technology developers to capture cross-cultural and institutional differences in MASS adoption (Ringbom, 2019; Kim and Schröder-Hinrichs, 2021).

Second, this study used aggregate constructs for institutional pressure and resource dependence. It did not separate different types of institutional pressures (coercive, normative, mimetic) or resource constraints (financial, technological, human) (DiMaggio and Powell, 1983; Pfeffer and Salancik, 1978). Future research should apply multi-dimensional measures to explore how these subcomponents interact and influence MASS adoption pathways. Third, the study treated niche innovation as a single construct, while MASS adoption involves layered innovations such as sensing systems, AI navigation, blockchain, and cybersecurity (Tsvetkova and Hellström, 2022; Fonseca et al., 2021). Future research should assess these sub-innovations separately to evaluate their specific impacts on operator attitudes toward MASS.

Fourth, the cross-sectional design limits the ability to observe changes over time (Podsakoff et al., 2003). Future longitudinal studies could track how institutional pressures, resource dependence, and niche innovation evolve as MASS technologies mature and regulations stabilize (Cohen and Levinthal, 1990; Geels, 2014). Fifth, while this study used the Multi-Level Perspective (MLP) as a backdrop, it focused on firm-level analysis. Future studies should align niche innovation pathways more explicitly within the MLP to examine how landscape pressures (e.g., decarbonization) and regime changes (e.g., safety regulations) interact with firm-level constraints in MASS transitions (Geels, 2011; Bergek et al., 2015). Sixth, this study did not include potential moderators and mediators like absorptive capacity (Cohen and Levinthal, 1990), organizational culture (Schein, 1990), and risk perception (Biermann and Harsch, 2017). Including these variables could help explain differences in organizational attitudes toward MASS.

Finally, while this study recognizes the potential of MASS for safety, efficiency, and sustainability, it notes that regulatory and liability challenges under frameworks like SOLAS and COLREGs may hinder adoption (Soyer and Tetterborn, 2019; Ahmed et al., 2024). Future research should explore legal readiness, certification practices, and liability-sharing models to support MASS business model transitions within evolving regulations. While the MLP is a strong framework for studying socio-technical transitions, it often emphasizes macro and meso-level processes while overlooking firm-level decision-making (Geels, 2014). Resource constraints, such as limits in technology, finance, and skilled labor, influence how firms adopt niche innovations like MASS (Pfeffer and Salancik, 1978; Biermann and Harsch, 2017). Although landscape and regime pressures drive change, firms' responses depend on their resources and dependencies (Tjan et al., 2021). Firms with fewer resources may delay adoption despite external pressures, indicating the need to integrate resource dependence theory within MLP analyses. Organizational learning, especially absorptive capacity (Cohen and Levinthal, 1990), also affects how firms adopt niche innovations. Firms with higher absorptive capacity can use landscape and regime pressures as strategic opportunities, while those lacking learning capabilities may resist change (Geels, 2014). Future research should explicitly combine resource constraints and organizational learning with MLP when analyzing maritime transitions.

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