Ng, A.K.Y., Poo, MC-P, Wang, T, Becker, A, Lau, Y-Y, Xu, TZ and Yang, Z

Dissecting climate adaptation strategies and planning of ports from different theoretical angles

Transport Economics and Management 3 (2025) 46–56

Contents lists available at ScienceDirect

Transport Economics and Management

journal homepage: www.journals.elsevier.com/transport-economics-and-management

Dissecting climate adaptation strategies and planning of ports from different theoretical angles

Adolf K.Y. NG [a,b,g], Mark C.P. POO [c], Tianni WANG [d], Austin BECKER [e], Yui-yip LAU [f], Tina Ziting XU [a,g,*], Zaili YANG [h]

[a] Faculty of Business and Management, BNU-HKBU United International College, Zhuhai, China
[b] UIC Institute for Advanced Study, BNU-HKBU United International College, Zhuhai, China
[c] Liverpool Hope Business School, Liverpool Hope University, Liverpool, UK
[d] College of Transport and Communications, Shanghai Maritime University, Shanghai, China
[e] Department of Marine Affairs, University of Rhode Island, Kingston, RI, USA
[f] Division of Business and Hospitality Management, College of Professional and Continuing Education, The Hong Kong Polytechnic University, Hong Kong
[g] International Centre for Resilient Supply Chains, BNU-HKBU United International College, Zhuhai, China
[h] Liverpool Logistics, Offshore and Marine Research Institute, Liverpool John Moores University, Liverpool, UK

ARTICLE INFO

Keywords:
Climate adaptation
Institutional system
Path dependence
Supply chain risk management
Stakeholder management

ABSTRACT

As the key nodes of globalization and international business, ports are exposed to the impacts of climate change, mainly because of their locations, including low-lying areas, coastal zones, and deltas. While there is increasing research on climate adaptation strategies and planning of ports, there is a lack of works that explain how scholars address the topic from different theoretical angles. This paper fills this gap by dissecting climate adaptation strategies and planning of ports from four main perspectives, including institutional systems, path dependence, supply chain risk management, and stakeholder management. It is a germane reminder to port decision-makers that effective climate adaptation is not limited to engineering technicalities but is an ideological issue that requires shifting existing political, economic, and social paradigms. Towards the end, we propose a process of effective adaptation planning to climate change impacts by ports.

1. Introduction

Climate change presents potential catastrophic risks to human lives and activities [9,35,58,64,82,81]. Recent studies warn of the rising risks posed by sea level increases, with projections indicating that by 2100, sea levels may rise significantly under various climate scenarios, creating acute vulnerabilities for coastal infrastructure [58,69,76]. Given the delayed responses and complexities in addressing climate change impacts, adaptation is now essential, particularly for critical nodes in global supply chains such as ports. Ports along shorelines are especially susceptible to climate-related risks affecting their facilities and operations [8,66]. Institutional and political dynamics further complicate adaptation efforts, as competing interests and policy ambiguities hinder effective climate resilience planning [9,47]. Many scholars argue that in addition to 'hard' adaptation strategies, such as levees and elevated infrastructure, 'soft' adaptation measures are necessary to build resilience against climate change impacts [47,83]. This paper discusses four theoretical frameworks that can port adaptation planning for ports within supply chains: institutional systems, path dependence, supply chain risk management (SCRM), and stakeholder management. Each framework offers insights that could help planners, practitioners, and researchers address barriers to adaptation, navigating the uncertainties and norms inherent in these complex systems.

The effects of climate change have far-reaching consequences for global infrastructure, with ports and maritime transportation systems particularly vulnerable to its impacts. However, they are increasingly exposed to extreme weather events such as hurricanes, rising sea levels, and floods, which threaten both infrastructure and operations. These impacts not only disrupt local economies but also have cascading effects on global supply chains, underscoring the need for resilient and adaptable port systems. Understanding the vulnerability of ports to climate-related disruptions is crucial for formulating effective risk management strategies. There has been a growing interest among researchers and practitioners to reduce the carbon footprint of maritime shipping to

* Corresponding author at: Faculty of Business and Management, BNU-HKBU United International College, Zhuhai, China.
E-mail address: xuziting@uic.edu.cn (T.Z. XU).

https://doi.org/10.1016/j.team.2025.01.001
Received 22 August 2024; Received in revised form 20 January 2025; Accepted 22 January 2025
Available online 31 January 2025

mitigate climate change effects by adopting operations management practices. These include operational decisions, such as speed reduction, berth scheduling, and route re-engineering to rationalize fuel consumption and reduce CO_2 emissions, to name a few. In the adaptation direction, there is growing interest in climate vulnerability assessments and risk assessments [53,65], but few have yet to implement operations management practices. With increasingly frequent and severe climate-related events, adapting to the impacts posed by climate change has become a key research topic influencing transport operation, infrastructure, planning and policymaking. For instance, it urgently requires illustrating the *status quo* regarding long-term risks posed by climate change on ports, including detailed analyses of the current measures and dilemmas in handling climate change issues and adaptation of planning to provide competent advice to port stakeholders. However, hitherto, most research on climate adaptation still focuses on the short-term impacts. There is insufficient research on systematically adapting to the effects of climate change on ports, especially in reducing uncertainties in decision-making, the development of effective public policies, and best practices with the input of different stakeholders. It does not deny the increasing scholarly contributions on the topic trying to explain the strategic and planning process from different angles, including us (e.g., [8,4,5,36,42,48,50,52,60,80,83,88,89]). Climate adaptation strategies require complex interactions between exposure, sensitivity, and adaptive capacity, and it requires active participation by all relevant stakeholders and the early involvement in the process. Nevertheless, there is a lack of articles that explain how scholars dissect climate adaptation strategies and planning of ports from different theoretical angles. Therefore, this paper first offers insights from managerial theories to provide a multi-disciplinary discussion and a conceptual framework for long-term climate adaptation strategies and planning of ports (Fig. 1). In this framework, institutional systems provide the structural foundation, defining the roles of policies, regulations, and norms in shaping adaptation strategies. Path dependency highlights how historical decisions and practices influence current adaptation strategies and constraints. Supply chain risk management serves as a practical framework to identify and mitigate risks associated with climate change, enhancing the resilience of both supply chains and ports. Stakeholder management acts as a connecting bridge, fostering collaboration and coordination among diverse stakeholders to balance competing interests and ensure the effective implementation of adaptation plans. This division enables a systematic analysis of the key mechanisms and challenges in port climate adaptation.

This study employs a multi-faceted methodology to analyze climate adaptation strategies and port planning case studies, integrating the application of theoretical frameworks. Specifically, our analytical approach includes the following steps:

1. **Case Selection**: We selected multiple representative port cases that exhibit varying strategies and outcomes in climate adaptation. The selection criteria include the geographical location of the ports, the climate risks they face, and their significance within global supply chains.
2. **Data Collection**: Data were gathered through literature reviews, policy document analysis, and interviews. The literature review encompassed relevant academic research, policy reports, and industry guidelines to ensure a comprehensive understanding of climate adaptation strategies. Interview subjects included port managers, policymakers, and relevant stakeholders to obtain first-hand information.
3. **Theoretical Framework Application**: We applied four main theoretical frameworks—institutional systems, path dependence, supply chain risk management (SCRM), and stakeholder management—to analyze and interpret the adaptation strategies within the case studies. These frameworks provided us with diverse perspectives to identify the key factors influencing port climate adaptation.
4. **Analytical Methods**: A qualitative analysis approach was employed to code and thematically analyze the collected data. By comparing the cases, we identified successful and unsuccessful adaptation strategies and explored the underlying reasons. Additionally, we utilized charts and models to visualize the analysis results, enhancing comprehension.
5. **Conclusion Formation**: Throughout the analysis, we continuously reflected on and revised our research hypotheses to ensure the validity and reliability of the conclusions. Ultimately, by combining insights from the theoretical frameworks with empirical data from the case studies, we proposed comprehensive recommendations for port climate adaptation.

The rest of the paper is as follows. Sections 2 and 3 explain how climate adaptation strategies and planning are viewed and explained by the institutional system and path dependency theory, respectively. Sections 4 and 5, dissect the topic from the perspectives of SCRM and stakeholder management, respectively. Finally, the conclusion can be found in Section 6. In the same section, we also propose a process of

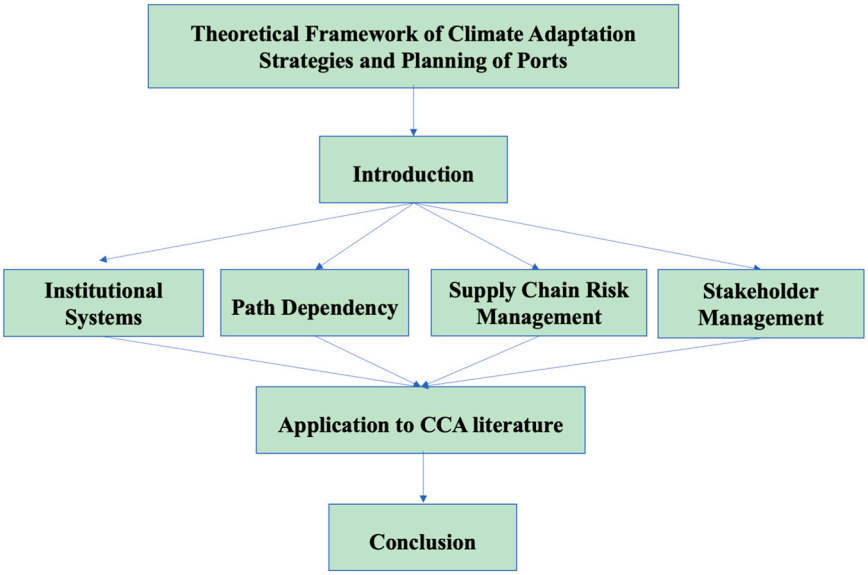

Fig. 1. Structure map. (Source: Authors).

effective adaptation to climate change impacts by ports.

2. Institutional systems

2.1. Theory

An institutional system can be understood as a set of standard mechanisms, establishments, and practices that structure relationships between agents, both public and private. It imposes preceding constraints on policymaking choices and strategic directions [30,43,73]. It countervails dramatic changes, restricts alternatives, and diminishes the rationalities of decision-making to predictable paths according to norms and practices based on culture and hegemonic values of the time [25,27] even when they may have become obsolete [33,55]. Institutional systems solidify generally accepted values into predictable practices to deter undesirable social outcomes due to individual actions. An institutional system can stretch [56,74] to deal with changing circumstances. The stretching usually involves two components, namely the institutional environment and the institutional arrangement. The former refers to informal conventions and norms of which organizations, being parts of a given community, should conform to gain legitimacy and general support, and sometimes made compulsory through legally binding rules and regulations [44]. Also, it includes the mindsets of individuals and political elites. The institutional environment forms the basis for compromise [29], operational characteristics, and receptiveness to new knowledge [10]. Institutional arrangement refers to agreements and organizational structures between agents to achieve certain objectives or programs governed by the institutional environment, like firms, bureaucracy, policies, and cooperative networks.

2.2. Applications

The influence of the institutional system on ports has been widely studied (e.g., [13,51,56]), but largely followed the neo-institutional approach that investigated how established institutional environment's structure guided decision-making. In this case, how and why the institutional system mattered remained mostly untouched. Facing circumstances like climate adaptation, institutional agents might take spontaneous initiatives to re-structure the institutional arrangements, as exemplified by the neo-liberal institutional and management reforms among global ports in the past decades. However, decision-making gets more complicated within an uncertain institutional environment consisting of individual mindsets, ambivalent interests, and diversified localities with individualistic and pluralistic traditions [22]. Climate adaptation planning had such an uncertain environment due to scarce legal standards, direct precedents, and readily transferrable scientific knowledge. This caused inadequate understanding, and thus inadequate input, from stakeholders and the public. With no direct paths to depend on, the institutional environment was a vacuum yet to be filled. Planning should provide clear guidance and practical actions to lead the direction of development, especially in the generation of first plans with many (untried) alternatives to choose from [67,68,86,87]. Further problems arise when the new circumstance has yet to reach a critical juncture [13] and all stakeholders do not yet deem significant transformation necessary or immediate.

In the production process, the port will inevitably be affected by extreme weather and cannot operate normally. For example, strong wind, heavy fog, heavy haze, blizzard, thunderstorm, typhoon and so on will affect the entry and exit of ships at the port, cargo unloading, resulting in a serious phenomenon of port pressure, and even cause the port to stop operation. The resilience of institutional environmental will increase, including much higher operational characteristics, and receptiveness to new knowledge with the uncertain disaster threat and adaptation need. Besides, the institutional arrangement will change a lot in the port organization to deal with the adaptation need (e.g., firms might make personnel or budget adjustments and bureaucracy formulate targeted policies). Ports, government, even international organization should increase the extreme climate change awareness and address climate change adaptation within climate adaptation planning and implementation, which may trigger re-structuring within port's institutional arrangements and a paradigm shift from previous planning norms and practices (see, e.g., [45]). For instance, the Port of Rotterdam in the Netherlands has implemented adaptive measures such as floating structures and raised dikes to combat sea-level rise and extreme weather, exemplifying contingency theory's emphasis on tailored, flexible strategies for environmental risks [8]. Similarly, the Port of Singapore employs predictive analytics for adaptive berth scheduling to manage disruptions caused by monsoon storms, highlighting contingency theory's value in enabling ports to respond dynamically to regional climate impacts [40].

To summarize, institutional systems play significant roles in climate adaptation planning and implementation. However, uncertainty in the institutional environment and the likely speculative attitude of major participants could strengthen the perception that political controversies would hinder implementation. Without resolving such challenges, climate adaptation plans might only become visionary guidance. This is not surprising, as the objective of the institutional system is to deter undesired shocks to societies due to individual actions [85]. Under such an uncertain institutional environment, the neo-liberal ideology, which emphasizes minimal public intervention [32], might continue to dominate port planning decisions. Under such, planners might muddle through the process by undertaking an evolutionary approach, even if they favor a more revolutionary one. Therefore, based on the port ownership and existing institutional organization, there needs to be more regulations to check whether the institutional environmental and institutional arrangements are reasonable, which can discover the problems in time and improve the institutional systems to better address the uncertain disaster threat and adaptation need.

3. Path dependency

3.1. Theory

Path dependence theory posits that prior conditions and events constrain and shape later outcomes and policy options [77]. It emphasizes the uncertainties in a process that the original form of phenomenon is impacted by initial conditions and the development of subsequent form restricted by 'lock-in' effects [77].

Path dependence is regarded as a vital theory in strategic planning and action. The basic point of path dependence in strategy research is that processes are not only contingent on the context where they occur, but also on their own histories [1]. One of critical implementations to the strategy process is that past decisions influence decisions in the future [17]. Also, a small event could result in huge changes from the perspective of strategic management [72]. Reflecting to the impacts of climate change on ports, there is little doubt that the past events' occurrence of climate change at a port (i.e., the frequency, severity, costs) will affect the decision making in a port planning. For example, after Superstorm Sandy, the Port of New York and New Jersey undertook a major planning effort to reduce risks to the port's infrastructure [71]. At the same time, the assumption that even a small event will trigger a change in strategic planning motivates planners to pay more attention to potential events and uncertainties posed by climate change. In other words, path dependence theory, as a creator of strategic possibilities, suggests that an adaptation port plan which considers the possibilities of potential uncertainties will be advantageous to the actions and interventions for climate change impacts in the future.

Gáspár [26] developed the concept of path dependence by combining it with path creation from a strategic perspective. Gáspár argued that the two concepts are not alternatives but closely connected with each other. The difference of path dependency and path creation relies on that the former emphases the capacity of future exploration,

while the latter is about the freedom to make decision and practice. Although both path dependence and path creation link the present with past and future, path creation highlights that agency is a component of nets of acting conduction that emerge relevant events and themes, and actors can impact the processes that conducted [78]. In Gáspár's model, "statistical sense (historical matters)" and "chaos theory (small change matters)" determine decision making (pp.95). This concept implies that the decision making for the future not only relies on the historical events but also "hopes, fears or expectation" (pp.95). Correspondingly, the interaction with the external environment and the future also improves the current decision and past experience in the long term. It can thus be inferred that the motivations of an adaptation port plan stem from two factors: the historical climate change event or small changes, and the prediction for climate change in the future. More importantly, a favorable adaptation port plan might also modify the existing port planning and operation and provide valuable experiences for other ports.

3.2. Applications

This concept has been widely applied to port studies [56]. There are three major streams that deal with the evolution of path dependence at ports. First, the long-term evolution of port systems focuses on the changing relationship between ports and port cities [54]. Second, the port governance systems treat ports as agglomerations of relevant industries and concerned with the unique development trajectories of ports and the diversity of management structures [12]. Third, the role of path dependence in institutional economics and geography and place implies the differences of institutional path dependence with the change in ways and places. As Notteboom et al. [57] suggest, all the stated streams involve dynamic interactions among institutional environment, government structure, and the port authority. With the impacts and uncertainties of climate change become increasingly serious and unpredictable, it requires port planners to consider the dynamics and stability in institutional economics, governance systems, and geographical conditions. Thus, a port's climate adaptation plan (usually through considering the potential risks and uncertainties) is a positive response to the path dependence theory. Also, every path dependence system has evolved thanks to different histories of their own systems and owing to the disproportionate impacts of climate change in different geographical areas. In this case, planners need to consider the specific conditions at every individual port. Decisions at an initial stage would affect the consequence of events in latter stages [62]. This encourages planners to consider the sequences of event occurrence and improve the elements in climate change when making an adaptation port plan.

Meanwhile, path dependence theory has been applied in studies of long-term strategic port planning [20], albeit in a more limited way. Pierson [63] and Kay [38] suggest that this concept is related to analysis of temporal dynamics, which emphasizes that significant changes in investment strategy and governance are often attributed to the shift of exogenous events (e.g., impacts of climate change) and the role of stakeholders. Since decision-making is a multi-party involved process, path dependence suggests that institutions in the path could be substituted when the existing institutions and conditions cannot approach the defined objective(s). Therefore, a long-term strategic plan based on real stakeholder inclusion is pivotal in governance change and development [20]. Case studies affirm this theory, such as research undertaken in the Port of Providence, Rhode Island, which found that many stakeholders play a role in building port resilience as they share both the risks and the resources upon which effective resilience depends [3]. Port authorities should thus seriously consider the uncertainties of climate change and its impacts on port stakeholders.

The province of Manitoba (MB), Canada, offers another illustrative case. The adaptation measures in MB are mainly based on the prevention against major risks (e.g., flooding at CentrePort Canada (CPC) (the major dry port in MB), frozen peatland and permafrost in Hudson Bay Railway (HBR)) [84]. However, several climate change uncertainties (e.g., tornadoes, heavy storms, extreme cold events) are inadequately considered when predict the climate change in the future. This phenomenon might partially explain the reason that both CPC and HBR lacks a specific adaptation plan for climate change. Another example is the port of Montreal, QC, Canada [80], current adaptation planning corresponds to the path dependency by linking the occurrence of low water level in the past to the prediction of low water level in the future. By doing so, electronic navigation is promoted to the port's stakeholders instead of dredging which poses environmental and other issues. Nevertheless, no matter for further starting or improving the adaptation planning in the two cases, the path dependence theory requires planners to establish a resilient framework to minimize climate change risks and uncertainties as well as concerned with the dynamic interaction among institutional environment, government structure and the landlord port authority. Path dependence theory is demonstrated in the adaptation choices of the Port of Montreal, which relies on historical data on fluctuating water levels to guide current climate adaptation strategies, like using electronic navigation over dredging, thus minimizing environmental impact while aligning with past practices [80]. Additionally, Europe's Port of Hamburg exemplifies path dependence through its evolving governance and infrastructure, which have historically adapted to changing water levels and storm surges over centuries [56].

To summarize, path dependence emphasizes the significant changes in investment strategy and governance are often attributed to the shift of exogenous events (e.g., climate change impacts) and role of stakeholders. Some ports in developed countries (e.g., Canada, UK, US) realize the impacts of climate change that occurred in the past and have adapted accordingly. Meanwhile, the motivations of an adaptation plan are consistent with the two critical factors in path dependence: the historical climate change event or small changes, and the prediction for climate change in the future. Above real cases illustrate that wisely applying climate adaptation strategies on ports can effectively relief the impacts of path dependence by which the butterfly effects of historical climate events or minor changes can be retarded while effective climate predictions with wider stakeholders' efforts can be amplified.

4. Supply chain risk management (SCRM)

4.1. Theory

With the topic of supply chain management and risk management each having been established and developed, their intersection area, SCRM, the definition attention in the past decades [61]. Although there is a variety of definition of SCRM, it is mainly related to the concept of risk and uncertainty in supply chains. In the context of SCRM, risk can be regarded as 'unreliable and uncertain resources resulting in supply chain interruption', while uncertainty can be interpreted as 'matching risk between supply and demand in supply chain processes' ([75], pp.26). Here we acknowledge that both the risks and uncertainties in SCRM are often connected to negative consequences that are difficult to distinguish [79].

Tang and Musa [75] defined supply chain risk following two conditions: "(i) events with small probability but may occur abruptly and (ii) these events bring substantial negative consequences to the system" (pp. 26). Meanwhile, since risks in supply chain are associated with the chance of happened ("hazard occurring") [11], as well as the consequences of these events (The Royal Society, 1992), as Brindley [11] interpreted from a quantitative perspective, Supply Chain Risk = Probability (of an event) * Business Impact (or severity) of the event related to the chance. More recently, with the design objective of supply chain extending to supply risk, security and sustainability, supply chain risk is also can be interpreted as "the extent to which supply chain outcomes are variable or are susceptible to disruption, and, thus, may be detrimental to a supply chain" ([91], pp.3403).

4.2. Applications

There are many studies investigating supply chain risks. In general, supply chain risks contain breakdowns, disruption, purchasing, and forecasting failures (see [37,90]). Supply chain disruption can be divided into two categories, namely unintentional and intentional disruptions. Unintentional disruption includes natural disasters (e.g., hurricanes, tornados, floods that disrupt supply paths, transportation, and manufacturing infrastructures) and man-made accidents (e.g., transport-related injuries that lead to delays, and further negative effects on products and services).

In this regard, a literature survey from 1995 to 2008 by Tang and Musa [75] categorizes supply chain risk by material flow risks, financial flow risks, and information flow risks. The risks in material flow stem from source, make and delivery aspects and represented by variables in sourcing flexibility, supplier selection, product monitoring, product process and design, and demand seasonality [23,39]. In financial flows, the risks come from unstable factors in exchange rate, price and cost, financial strength of supply chain partners and financial handling and practice [31,37]. Finally, in information flow, the risks include information accuracy, information system security and disruption [41].

With changes in the market and the long-term consideration of strategic decisions in supply chain network design, uncertainty plays a prominent role in supply chain management. There has been limited attention on lower-impact and unintentional risks that involve climate change in supply chains. SCRM, as a major part of supply chain management, requires designing a dynamic supply chain network structure by considering both risks and uncertainties to manage the product flow throughout the system to predict, arrange, and recover from disruptions [2]. Therefore, a long-term adaptation plan for climate change can contribute to minimize risks and uncertainties and increase the dynamics in SCRM.

In this case, Tang and Musa [75] show that, since 2004, there have been more publications on this topic by both academics and professionals. Discussion topics include challenges and opportunities of outsourcing to low-cost countries, information security and sharing, partner relationship, economy, environmental, and political issues in supply chains, to name but a few. Nevertheless, there are still significant gaps in SCRM research. Although efforts have been extended to combine material and cash flows, most literature relies on the issues in material flows, especially in supplier selection. Even though enough awareness has been given to SCRM in the industry, the focus still relies on qualitative aspects (e.g., descriptive model, conceptual model) and there is inadequate quantitative research (e.g., quantitative model, risk-related information, robust planning, system dynamics, reverse logistics). Robust adaptation plan for risks and uncertainties posed by climate change should combine qualitative and quantitative methods.

Integrating practical applications of SCRM, ports can utilize frameworks such as the Bow-Tie method and Fault Tree Analysis (FTA) to identify vulnerabilities and develop preventive strategies, as suggested by Zsidisin et al. [91]. Additionally, quantitative risk assessment tools like Monte Carlo simulations can model the probability of various outcomes, aiding in understanding the range of potential impacts and supporting decision-making under uncertainty, as highlighted by Paulsson [61]. Scenario planning and stress testing can be employed to develop strategies under different climate change scenarios and evaluate the resilience of port infrastructure against extreme weather events, a method discussed by Baghalian et al. [2]. Early warning systems, leveraging real-time data and predictive analytics, can provide proactive alerts of impending climate-related risks, allowing for timely mitigation measures, as Tang and Musa [75] have noted.

Although there is widespread recognition that ports are key nodes along supply chains and supply chain management should be applied to the port sector, port risk management has received little attention in the literature. Research in SCRM tends to focus on identification of disruptions and mitigation countermeasure for catastrophic events [28]. Meanwhile, existing research tends to focus on risk factors in changing demands and marketplace in supply chains (e.g., [16]). However, given the fragility and complexity of port-focal supply chains [49], adaptation planning by considering uncertainties in climate change should be applied in port risk management. On the other hand, in Canada, CPC, HBR, and the port of Montreal have concerns with the risks posed by climate change. In particular, the port of Montreal used a comprehensive risk-analysis procedure in port planning. Nevertheless, all three of them have yet to consider the potential uncertainties in the entire supply chain. After the Great Hanshin Earthquake, Japan's Port of Kobe was reconstructed with enhanced SCRM, bolstering its capacity to withstand future climate impacts [6]. Similarly, Caribbean ports, which face frequent hurricanes, invest heavily in structural and operational resilience measures to minimize downtime and ensure quick recovery after extreme weather events, demonstrating SCRM theory's role in fostering disaster-ready port infrastructure [59].

To summarize, SCRM requires designing a dynamic supply chain network structure by considering both risks and uncertainties to manage the product flow throughout the system to predict, arrange and recover from disruptions [2]. In the case of port of Montreal [80], the entire port supply chain is impacted due to the issue of lower water. As the shipping carriers can impose USD200 surcharge per container on the shippers if the vessels are unfilled, the increased cost could pass upstream suppliers to downstream customers so as to deteriorate the advantages of the port compared to other competitors (e.g., Port of New York). Furthermore, when shipping business is constrained by such issue, containers may need to be stocked in hinterland until the water level arise again, which also calls for inland freights to supplement. To deal with lower water issues, vertical and horizontal cooperations are both encouraged. Indeed, some external supports including infrastructural and financial subsidization from government, qualification authentication from marine associations (e.g., Green Marine) and academic study from colleges and NGOs (e.g., University of Montreal) have been given. Nerveless, higher public participant, in particular regarding social and environmental accessibility (e.g., in capital dredging), as well as supports from external stakeholders (e.g., shippers, carriers, terminal operations in other port) may further help climate adaptation and sustainable development in Port of Montreal.

In addition, both risks and uncertainties in SCRM are related to negative consequences in most literatures, the positive impacts posed by climate change (e.g., the longer shipping season in Hudson Bay and in the port of Montreal because of global warming) can be considered. Port's SCRM may examine ways to take advantage of these positive impacts. Although path dependence theory has been applied in strategic port planning research (Doom *et al.*, 2013), historical conditions cannot serve as the only benchmark for future decision-making, considering the tendency of more intensive, frequent, and unstable climate patterns. SCRM addresses this deficiency by emphasizing the concept port supply chain and quantifying the risks and potential uncertainties to design a dynamic supply chain network. Nevertheless, SCRM alone might not address how to minimize the risks and uncertainties and maximize the benefits of stakeholders in the entire supply chains that leads to the utilization of stakeholder management.

5. Stakeholder management

5.1. Theory

Stakeholder management theory originates from the field of strategy, where a stakeholder is defined as 'any group or individual who can affect or is affected by the achievement of the organization's objective' (Freemen, 1984, pp.53). In this case, stakeholder management theory is '"managerial" and recommends the attitudes, structures, and practices that, taken together constitute a stakeholder management philosophy' ([19], pp.67). Smudde and Courtright [70] conduct holistic research in stakeholder management based on three primary questions, as follows:

1. How are stakeholders created?
2. How can relationships with stakeholders be maintained?
3. How can relationships with stakeholders be improved? (pp.137).

In several Canadian cases [80,84], the port as its core enterprise has played a key role in combining and coordinating its service providers with customers into an effective system. The multiple stakeholders, in general, involve shipping companies, shippers, terminal operators, environmental and community advocates, government and other parties [7], including shipping companies like Maersk, which operates one of the world's largest container shipping networks and relies on efficient port operations; shippers such as Walmart, a major retailer that ships substantial volumes of goods through various ports; terminal operators like Hutchison Ports, managing terminals globally, including the Port of Felixstowe; environmental advocates such as the Sierra Club, which champions cleaner shipping practices to mitigate emissions in port cities; community advocates, for instance, the Port of Los Angeles Community Advisory Committee, representing local residents' interests and concerns about port activities; government bodies like the U.S. Federal Maritime Commission, which regulates the maritime industry; and other parties, including the American Association of Port Authorities, representing the collective interests of port authorities.

Meanwhile, in response to the demands of strategic planning, Smudde and Courtright [70] elaborate on two realms of stakeholder management reactive and proactive stakeholder management. Specifically, reactive stakeholder management focuses on past activities that have affected relationships with stakeholders. Through a single loop learning process, reactive stakeholder management highlights the need of drawing past experiences, including what went right and wrong, what deficiencies have been eliminated or reduced, and what could be improved in the future. Proactive stakeholder management is concerned with future activities to produce opportunities for cooperation between stakeholders and organizations. The proactive concept involves a double-loop learning process where an organization is adaptively adjusting to the management process in a changeable environment. The advantage of proactive stakeholder management relies on that, *via* an adaptive and tactical design, it would maximize/enhance the strengths, minimize the weakness, generate opportunities, and screen threats for success in the future. Accordingly, climate adaptation strategies and planning of ports is consistent with proactive stakeholder management theory in predicting the potential damages, crises, and disasters, managing the relevant personals who are and will be stakeholders and improving the stakeholder relationships.

5.2. Applications

Fassin [21] analyzes strategy management, reciprocity, and responsibility. Stakeholders can be broken down into four categories based on legitimacy: 'stakeowners', the internal constituents having a real stake in an organization; 'stakewatchers', pressure groups influencing the organization; 'stakekeepers', mainly regulators imposing external control and regulations on the organization; and 'stakeseekers', those seeking a voice in the organization's decision-making [34]. While stakeholder theory focuses on corporate responsibility towards a firm's stakeholders [24] from the strategic perspective, Fassin [21] argues that stakeholders could influence the organization (stakeholder reciprocity and responsibility). The stakeholder reciprocity could be limited by the stakeowners who legislate stakes and loyal partners are involving multiple benefits; meanwhile, the stakeholder in stakeholder responsibility refers to the organization's stakeholders excluded from the stakeowners. To construct a long-term commitment and responsibility requires paying more attention to the reciprocity from stakeowners and their moral responsibility including loyalty, fairness, and ethical treatment. At the same time, stakewatchers and stakeseekers who formulate their strategy from the political resource perspective should not underestimate their ethical responsibility. Port planners are encouraged to recognize the diversified roles within the stakeholder networks and be concerned with the reciprocity of stakeonwers and responsibility of different organizational stakeholders when creating an adaptation plan. Stakeholder engagement is critical in ports' CCA efforts worldwide. In Australia, the Port of Melbourne's adaptation initiatives showcase effective stakeholder engagement, as the port collaborates with local councils, environmental organizations, and the public to ensure sustainable climate resilience practices [70]. The Port of Durban in South Africa also illustrates the importance of alignment among diverse stakeholders by involving community organizations and government entities in flood management initiatives, securing both financial and social support for adaptation [21].

Existing literature proves guidance for stakeholder management in port planning and governance. First, stakeholder management reflects the demands of increasingly intensive competition and integration of port-included multimodal supply chains [40]. Port supply chains imply that the port as its core enterprise, combines, and coordinates service providers (e.g., transport, handling, inventory) with customers (e.g., shippers, shipping companies) into an effective system that distributes the correct number of goods to the right place, at the right time, and to maximize the efficiency and profits of the entire supply chain [14]. This requires a comprehensive stakeholder management process, where planners emphasize the roles, responsibilities, and relevance of stakeholders, and consider internal and external uncertainties in port-focal supply chains. Dooms et al. [20] point out, the divergent preferences of stakeholders for port development, and emphasize the challenge of balancing the multiple (sometimes conflicting) benefits to stakeholders in the port-focal supply. Therefore, a strategic port plan based on stakeholder management would contribute to change in the broader port region and port supply chains.

Second, port stakeholders, involving shipping companies, shippers, terminal operators, government, logistics service providers and other parties associated with port industries, are expected to create, and sustain value in the same customer value chain [18,40]. Regional port governance broadens the scope of stakeholders to policymakers at different hierarchies, community groups, and market players at different ports. The complexity of stakeholder management in port regional governance calls for the collaboration of multiple parties through joint projects and technological innovation, all of which is supported by a strategic port planning of policymakers, to minimize the conflicts among stakeholders and maximize common benefits [40]. Such logic also applies to port planning on climate adaptation. In response to the increasing risks and uncertainties of climate change on ports in a wider area, port planning must accommodate the change of the external environment, encourage an extensive participation of stakeholders, reduce the risks and conflict among the port stakeholders, create a technology framework, and tailor to specific conditions by joint efforts against climate change impacts.

To effectively involve stakeholders in climate adaptation planning for ports, it is essential to develop inclusive engagement strategies that address the specific needs and interests of various stakeholder groups, ensuring that even the underrepresented voices are not only heard but also integrated into the process. This involves establishing robust communication channels and fostering an environment conducive to open dialogue, where collaborative workshops and forums become platforms for active stakeholder participation in discussions and problem-solving related to climate adaptation. Furthermore, integrating stakeholders into the decision-making process allows their input to influence the direction and implementation of strategies, thereby increasing ownership and commitment to the plans. To ensure the effectiveness of these engagements, it is crucial to implement monitoring and feedback mechanisms that assess the impact of stakeholder involvement on the planning process and provide stakeholders with insights on how their contributions have been incorporated into the plans, thus fostering a cycle of continuous improvement.

To summarize, stakeholder management reflects the demand of

increasingly intensive competition and integration of port supply chains [40]. However, it is still a significant challenge to coordinate all the stakeholders in adapting to risks and uncertainties. For example, in the study of CentrePort and the Hudson Bay Railway aforementioned [84], climate change influenced the port and its supply chains in both positive and negative ways. The Provincial and Federal governments have made corresponding action plans, initiatives and considerable infrastructure investments in the area. CentrePort, simultaneously, has started with a high standard in adapting to flooding as a primary risk posed by climate change in Manitoba. Rail upgrades have also been undertaken to remedy the stability problems of frozen peatland and permafrost posed by climate change. Nevertheless, it is found neither CentrePort nor Hudson Bay Railway has a specific adaptation plan for climate change, which is mainly attributed to the deficiencies of all-round stakeholder management which includes top-down policies, prevention awareness and experience sharing in adapting climate change uncertainties. Increasing climate impacts require a stakeholder management process through which port planners emphasize the role, responsibility, and relevance of stakeholders, enhance the public participation in decision making, and consider both risks and uncertainties in port supply chains. The complexity of stakeholder management calls for the collaboration of multiple parties through joint projects and technological innovation. Initiating or improving a specific adaptation plan for climate change can minimize the conflicts among stakeholders and maximize their common benefits in the future. As pointed out Messner et al. [46], the effective application of stakeholder management might contribute to the reconstruction and improvement of the ports' adaptation-planning paradigm.

6. Conclusion

Recognizing the inadequacy of research that explains how scholars dissect climate adaptation strategies and planning of ports from different theoretical angles, this paper examines the topic from four major theoretical perspectives, including institutional system, path dependence, SCRM, and stakeholder management. It is a germane reminder to port planners and policymakers that effective climate adaptation is not just limited to engineering technicalities, but an ideological issue that needs a fundamental shift of existing political, economic, and social paradigms. Nevertheless, no matter from which theoretical angle, the implementation of climate adaptation planning would not be successful unless decision-makers can develop an iterative approach to adaptation. One proposed process of effective adaptation to climate change adaptation was recently developed in a joint effort between the US Army Corps of Engineers (USACE) and the US Cyber and Infrastructure Security Agency (CISA) for the maritime sector (Fig. 2). In this process, the user moves through four stages of an assessment: pre-assessment, design assessment, conduct assessment, and implement findings. These broad stages consist of several smaller steps and decisions for each, all of which require the implementation, or at least consideration, of many aspects of the theories discussed in this paper. (e.g., institutional systems, risk management, path dependence, stakeholder management). Guides such as this can provide a road map for organizations, or the consultants that they contract with, to create an effective process in coordination with other interested parties.

These four theoretical frameworks including: institutional systems, path dependence, supply chain risk management (SCRM), and stakeholder management planners, practitioners, and researchers to overcome myriad barriers in supply chains. The combination of some of these four strategies will occur more obvious positive influence. For example, combing the advantages of institutional systems, path dependence can will be advantageous to consummate the institutional environment and institutional arrangement regarding the actions and interventions for climate change impacts in the future. Besides, the focused contents of stakeholder management especially for the port stakeholders are still essential components of the analysis of supply chain risk management, leading to the combined strategies can affect

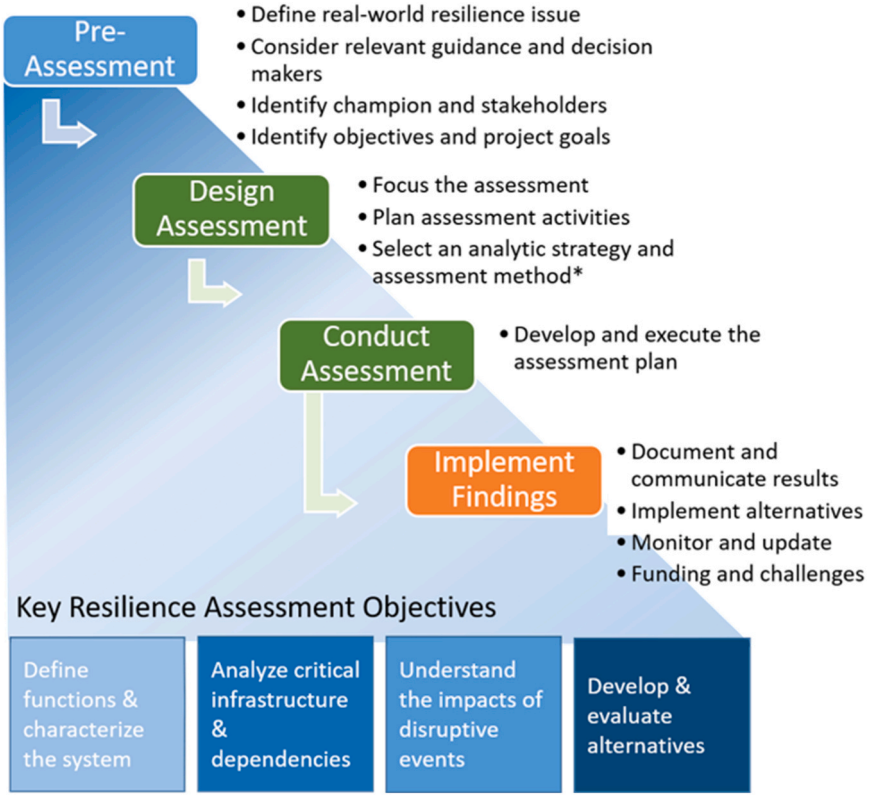

Fig. 2. Example of proposed process of effective adaptation to climate change impacts. (Source: Cybersecurity and Infrastructure Security Agency (CISA) and US Army Corps of Engineers Engineering Research and Development Center (ERDC) (In Review)[15]).

Table 1
Summary of CCA Literature Insights.

CCA Literature Key Points	Institutional Systems	Path Dependence	Supply Chain Risk Management (SCRM)	Stakeholder Management
Key Findings	Institutional barriers such as policy ambiguity and regulatory constraints often hinder the implementation of CCA measures.	Past investment decisions in port infrastructure limit the range of adaptation options available.	CCA measures are often reactive rather than proactive due to supply chain disruptions.	Engaging a diverse range of stakeholders is crucial for the success of CCA initiatives.
Issues	Conflicting interests among different port stakeholders can impede effective CCA planning.	The legacy of previous port development paths influences current adaptation strategies.	Supply chain disruptions due to climate events pose significant risks to port operations.	Balancing the interests of various stakeholders is a challenge in CCA planning.
Trends	There is a growing trend towards integrating CCA into port planning and operations.	Ports are increasingly recognizing the need to break away from historical development paths to adapt to climate change.	The focus on risk management in supply chains is shifting towards a more holistic approach that includes climate risks.	There is a trend towards more inclusive and participatory approaches in stakeholder engagement.
Processes	The policy-making process for CCA in ports is often complex and involves multiple levels of government.	Adaptation strategies in ports are influenced by the path-dependent nature of technological choices and institutional practices.	Risk assessment and mitigation processes are being integrated into supply chain management.	Collaborative decision-making processes are being adopted to involve stakeholders in CCA planning.
Actors	Port authorities, government agencies, and international organizations play key roles in CCA.	Port authorities and private operators are constrained by past decisions and investments.	Shipping companies, terminal operators, and logistics providers are critical in managing supply chain risks.	A wide range of actors including local communities, environmental groups, and industry partners, are involved in CCA.

more rational to guide the port planners.

The table above demonstrates how the key points from the existing CCA literature can be systematically mapped against each of the four perspectives discussed in this paper: Institutional Systems, Path Dependence, Supply Chain Risk Management (SCRM), and Stakeholder Management. While the current manuscript provides a thorough qualitative analysis of climate adaptation strategies in ports, the inclusion of quantitative data would significantly bolster the findings. By integrating statistical analyses that quantify the impacts of climate change on port operations, such as disruptions in cargo throughput due to extreme weather events or the economic costs associated with sea-level rise, the paper could offer a more comprehensive understanding of the practical implications of climate risks. Additionally, incorporating metrics on stakeholder engagement, such as response rates to surveys, the number of collaborative initiatives, or the degree of stakeholder satisfaction with the planning process, would provide empirical evidence supporting the theoretical claims made regarding the effectiveness of various stakeholder management strategies. This blend of quantitative and qualitative research methods would not only enhance the academic rigor of the study but also offer practical insights for port authorities and policymakers seeking to implement data-driven climate adaptation plans.

Table 2 presents a comparative analysis of four theoretical frameworks—Institutional Systems, Path Dependence, Supply Chain Risk Management (SCRM), and Stakeholder Management—highlighting their key dimensions and their contributions to understanding Climate Change Adaptation (CCA) in ports. It outlines the scope, focus, units of analysis, key actors, and explanatory relations of each framework, demonstrating how they collectively enhance our comprehensive grasp of the complexities involved in port adaptation to climate change. This synthesis underscores the need for a multifaceted approach to research and policy in the port sector's response to climate challenges. Building on the insights from theoretical analysis and case studies, port management and planning practitioners should consider aligning their adaptation strategies with broader institutional systems, leveraging historical path dependencies to inform future planning, and integrating supply chain risk management tools to identify vulnerabilities and develop preventive strategies. Enhancing stakeholder engagement, adopting an adaptive planning process, investing in technology and innovation, and building capacity through training and knowledge

Table 2
Theoretical Frameworks and Their Contributions to Understanding CCA in Ports.

Theoretical Framework Dimensions	Institutional Systems	Path Dependence	Supply Chain Risk Management (SCRM)	Stakeholder Management	Contribution to CCA in Ports
Scope	Focusing on institutions and governance	Historical development and its impact on current and future options	Management of risks and uncertainties in supply chains	Focusing on relationships among stakeholders	Provides a comprehensive view of the institutional barriers and facilitators in CCA
Main Focus	Rules, norms, and practices that influence behavior	The influence of past events on current and future path	Identification, assessment, and mitigation of supply chain risks	Managing the interests and expectations of various stakeholders	Offers insights into the historical constraints and opportunities for CCA
Main Units of Analysis	Institutions, policies, and regulations	Pathways of development and their constraints	Supply chain networks and nodes	Stakeholder groups and their interactions	Highlights the regulatory and policy contexts shaping CCA
Key Actors	Policymakers, institutions, regulators	Historical events and decisions, current decision-makers	Supply chain managers, logistics providers	Stakeholders with varying interests and power	Identifies the historical and current actors influencing CCA paths
Main Explanatory Relations	How institutions shape policy and behavior	How past decisions limit future options	How supply chain risks are managed	How stakeholder interests are balanced	Explains the dynamics of stakeholder interactions in CCA
Contribution to CCA in Ports	Provides a framework for understanding policy and institutional barriers	Offers a historical perspective on adaptation strategies	Enhances understanding of supply chain vulnerabilities and resilience	Emphasizes the importance of inclusive planning and management	Each theory provides unique insights into the complexities of CCA in ports, highlighting different aspects that contribute to a holistic understanding

sharing are also crucial for building resilience and sustainability in the face of climate change. These strategies, while grounded in theory, offer practical steps that ports can take to address the immediate and long-term challenges posed by climate change, emphasizing the need for collective and concerted efforts to secure the future of global trade and local economies.

This study provides a systematic analysis of how different theoretical frameworks can be applied to enhance CCA in ports. Contingency theory underscores the importance of adaptive strategies that are responsive to varying environmental risks, supporting ports in tailoring their approaches to specific climate challenges. Stakeholder theory highlights the critical role of engaging diverse stakeholders, enabling ports to incorporate broader perspectives and secure essential support for long-term CCA initiatives. Together, these theories provide a comprehensive framework for understanding and addressing the complex challenges of CCA in the port sector. They offer practical guidelines for developing adaptive, inclusive, and resilient CCA strategies, while also suggesting avenues for future research, such as the development of adaptive governance models and the examination of successful stakeholder engagement practices. By applying these theories, this study not only enhances theoretical understanding but also provides actionable insights for ports seeking to strengthen their resilience in the face of climate change.

This study highlights how each theoretical framework—such as contingency theory, stakeholder theory, and resilience theory—addresses key challenges in CCA for ports. Specifically, contingency theory emphasizes the need for ports to adopt flexible and adaptive strategies that can respond effectively to different environmental risks. Stakeholder theory underscores the importance of engaging a broad spectrum of stakeholders, from local communities to international regulatory bodies, in decision-making processes for CCA. Resilience theory further provides insights into building structural and operational resilience within port networks to withstand extreme weather events.

These theories collectively suggest avenues for future research, such as examining the role of adaptive governance frameworks in enhancing port resilience and identifying stakeholder engagement strategies that optimize resource allocation for CCA initiatives. Applying these theoretical perspectives enables a deeper understanding of CCA challenges than focusing solely on practical approaches, as they allow for the integration of established lessons from other port studies. For instance, lessons from ports that have successfully navigated complex stakeholder relationships or implemented resilience-building practices can inform more robust CCA strategies in emerging contexts.

The increasing frequency and intensity of climate events, such as extreme weather, rising sea levels, and flooding, underscore the urgency for ports to not only adapt but to proactively prepare for a future where such events are the norm rather than the exception. The consequences of inaction are far-reaching, impacting not just the port's infrastructure and operations, but also the global supply chains they support and the communities they serve. Therefore, the call to action for port planners, policymakers, and all stakeholders involved is to move beyond mere awareness and to implement the adaptive strategies and planning discussed in this paper. The time for decisive action is now, as the risks and costs of inaction far outweigh the challenges of adaptation. The future resilience of ports and their ability to sustain global trade and local economies in the face of climate change depends on the collective and concerted efforts taken today.

Through a detailed discussion from different theoretical angles and providing an effective process, we strongly confirm that this paper has contributed to the literatures and ongoing discussions on effective climate adaptation planning in both ports and supply chains. It addresses deficiencies that may hinder effective climate adaptation and highlights structural principles of climate adaptation planning, and existing loopholes that require paradigm shift solutions. The impacts posed by climate change to the world will become more explicit in the future, necessitating more research to reduce uncertainties in decision-making. People from different sectors must be warned, including operators and public, to work together on climate change mitigation campaigns, but also adaptation measures. Additionally, stakeholders involved in the port sectors, such as shipping firms, shippers, terminal operators, the government, logistics service providers, and others, may help with climate adaptation and sustainable growth. Also, it is possible to implement into the network modelling to visualize the changes in global shipping networks in the coming years. Finally, we do not claim that this paper has covered all the theoretical angles. However, it offers useful theoretical insights on how climate adaptation strategies and planning of ports and supply chains can and should be developed. We intend it to serve as a platform to conduct more quality research on this topic from different theoretical perspectives; to analysis the possible interactions among four theoretical angles and to study the specific institutional differences from major markets for future research.

CRediT authorship contribution statement

NG Adolf K.Y.: Writing – original draft. **POO Mark C.P.:** Formal analysis. **Wang Tianni:** Formal analysis. **BECKER Austin:** Formal analysis. **LAU Yui-yip:** Investigation. **XU Tina Ziting:** Writing – review & editing, Conceptualization. **YANG Zaili:** Methodology.

Declaration of Competing Interest

The authors have no known conflict of interest.

Acknowledgments

We gratefully acknowledge the support from the BNU-HKBU United International College Research Funds (R72021201), National Natural Science Foundation of China (UICR600041), and the Shanghai Pujiang Talent Program (21PJC068). An earlier version has been presented at the World Transport Convention (WTC) 2023.

Data availability

The data that has been used is confidential.

References

[1] W.B. Arthur, Y.M. Ermoliev, Y.M. Kaniovski, Path-dependent processes and the emergence of macro-structure, Eur. J. Oper. Res. 30 (3) (1987) 294–303.
[2] A. Baghalian, S. Rezapour, R.Z. Farahani, Robust supply chain network design with service level against disruptions and demand uncertainties: A real-life case, Eur. J. Oper. Res. 227 (1) (2013) 199–215.
[3] A. Becker, Using boundary objects to stimulate transformational thinking: storm resilience for the Port of Providence, Rhode Island (USA), Sustain. Sci. 12 (2017) 477–501.
[4] A. Becker, M. Acciaro, R. Asariotis, E. Cabrera, L. Cretegny, P. Crist, M. Esteban, A. Mather, S. Messner, S. Naruse, A.K.Y. Ng, S. Rahmstorf, M. Savonis, D.W. Song, V. Stenek, A.F. Velegrakis, A note on climate change adaptation for seaports: a challenge for global ports, a challenge for global society, Clim. Change 120 (4) (2013) 683–695.
[5] A. Becker, A. Hippe, E. Mclean, Cost and materials required to retrofit US seaports in response to sea level rise: A thought exercise for climate response, J. Mar. Sci. Eng. 6 (4) (2018) 155.
[6] A. Becker, S. Inoue, M. Fischer, B. Schwegler, Climate Change Impacts on International Seaports: Knowledge, Perceptions, and Planning Efforts among Port Administrators, Clim. Change 110 (1-2) (2012) 5–29, 2009.
[7] Becker, A., Matson, P., Fischer, M., Mastrandrea, M.D. (2014) Toward Seaport Resilience for Climate Change Adaptation: Stakeholder Perceptions of Hurricane Impacts in Gulfport (MS) and Providence (RI). *Progress in Planning*.
[8] A. Becker, A.K.Y. Ng, D. McEvoy, J. Mullett, Implications of climate change for shipping: ports and supply chains, Wiley Interdiscip. Rev.: Clim. Change 9 (2) (2018) wcc.508.
[9] R. Biesbroek, J.E. Klostermann, C.J. Termeer, P. Kabat, On the nature of barriers to climate change adaptation, Reg. Environ. Change 18 (3) (2018) 847–858.
[10] B. Boxer, Societal Contexts of Ocean Pollution Science: Cross-National Comparisons, Glob. Environ. Change 1 (2) (1991) 139–156.
[11] C. Brindley (Ed.), Supply Chain Risk, Ashgate, Aldershot, 2004.
[12] M. Brooks, K. Cullinane, Devolution, Port Governance and Performance. Research in Transport Economics, 17, Elsevier, Dordrecht, 2007.

[13] E. Buitelaar, A. Lagendijk, W. Jacobs, A theory of institutional change: Illustrated by Dutch City-Provinces and Dutch Land Policy, Environ. Plan. A 39 (2007) 891–908.
[14] J. Cheng, Y. Zhu, The construction of port logistics information platform based on port supply chain, *Int. Conf. E-Bus. E-Gov.*, May 2011 (2011) 1–4.
[15] Cybersecurity and Infrastructure Security Agency (CISA) and US Army Corps of Engineers Engineering Research and Development Center (ERDC) (In Review). Resilience Assessment Guide for Ports and the Maritime Transportation System, Arlington, VA and Washington, DC.
[16] K. Das, Integrating effective flexibility measures into a strategic supply chain planning model, Eur. J. Oper. Res. 211 (1) (2011) 170–183.
[17] David, P. (1990). *Understanding the economics of QWERTY: The necessity of history*.
[18] J. Debrie, V. Lavaud-Letilleul, F. Parola, Shaping port governance: the territorial trajectories of reform, J. Transp. Geogr. 27 (2013) 56–65.
[19] T. Donaldson, L.E. Preston, The stakeholder theory of the corporation: Concepts, evidence, and implications, Acad. Manag. Rev. 20 (1) (1995) 65–91.
[20] M. Dooms, A. Verbeke, E. Haezendonck, Stakeholder management and path dependence in large-scale transport infrastructure development: the port of Antwerp case (1960–2010), J. Transp. Geogr. 27 (2013) 14–25.
[21] Y. Fassin, Stakeholder management, reciprocity, and stakeholder responsibility, J. Bus. Ethics 109 (1) (2012) 83–96.
[22] R. Fishman, The American Planning Tradition: Culture and Policy, The Woodrow Wilson Center Press, Washington, DC, 2000.
[23] K.R. Fitzgerald, Big savings, but lots of risk, Supply chain Manag. Rev. v. 9 (9) (2005) 16–20. Dec. 2005.
[24] R.E. Freeman, J.S. Harrison, A.C. Wicks, Managing for Stakeholders: Survival, Reputation, and Success, Yale University Press, 2007.
[25] M. Fuchs, A. Scharmanski, Counteracting Path Dependencies: Rational Investment Decisions in the Globalising Commercial Property Market, Environ. Plan. A 41 (11) (2009) 2724–2740.
[26] T. Gáspár, Path dependency and path creation in a strategic perspective, J. Futures Stud. 15 (4) (2011) 93–108.
[27] J. Glassman, Transnational Hegemony and US Labor Foreign Policy: Towards a Gramscian International Labor Geography, Environ. Plan. D: Soc. Space 22 (4) (2004) 573–593.
[28] H. Guerrero, D. Murray, R. Flood, A model for supply chain and vessel traffic restoration in the event of a catastrophic port closure, J. Transp. Secur. 1 (2) (2008) 71–80.
[29] A. Gutmann, D. Thompson, The Spirit of Compromise, Princeton University Press, Princeton, NJ, 2012.
[30] P.A. Hall, R.C.R. Taylor, Political Science and the Three New Institutionalisms, in: K. Soltan, E. Soltan, E.M. Uslaner (Eds.), Institutions and Social Order, University of Michigan Press, Ann Arbor, 1998, pp. 14–44.
[31] R. Hartley-Urquhart, Managing the financial supply chain, Supply Chain Manag. Rev. 10 (6) (2006).
[32] D. Harvey, A Brief History of Neoliberalism, Oxford University Press, Oxford, 2005.
[33] Hodgson, G. (1993) *Economics and Evolution: Bringing Life Back in Economics*, Polity, Cambridge.
[34] B. Holzer, Turning stakeseekers into stakeholders: A political coalition perspective on the politics of stakeholder influence, Bus. Soc. 47 (1) (2008) 50–67.
[35] IPCC. (2021). *Sixth assessment report: Climate change 2021 - The physical science basis; Climate change 2022 - Impacts, adaptation and vulnerability; and Climate change 2022 - Mitigation of climate change*.
[36] C. Jiang, S. Zheng, A.K.Y. Ng, Y.E. Ge, X. Fu, The climate change strategies of seaports: mitigation vs. adaptation, Transp. Res. Part D: Transp. Environ. 89 (2020) 102603.
[37] M.E. Johnson, Learning from toys: lessons in managing supply chain risk from the toy industry, Calif. Manag. Rev. 43 (3) (2001) 106–124.
[38] A. Kay, A critique of the use of path dependency in policy studies, Public Adm. 83 (3) (2005) 553–571.
[39] O. Khan, M. Christopher, B. Burnes, The impact of product design on supply chain risk: a case study, Int. J. Phys. Distrib. Logist. Manag. 38 (5) (2008) 412–432.
[40] J.S.L. Lam, A.K.Y. Ng, X. Fu, Stakeholder management for establishing sustainable regional port governance, Res. Transp. Bus. Manag. 8 (2013) 30–38.
[41] H.L. Lee, The triple-A supply chain, Harv. Bus. Rev. 82 (10) (2004) 102–113.
[42] Y. Lin, A.K.Y. Ng, A. Zhang, Y. Xu, Y. He, Climate change adaptation by ports: the attitude of Chinese port organizations, Marit. Policy Manag. 47 (7) (2020) 873–884.
[43] J.G. March, J.P. Olsen, Rediscovering Institutions: The Organizational Basis of Politics, The Free Press, New York, NY, 1989.
[44] R. Martin, Institutional Approaches in Economic Geography, in: E. Sheppard, T. Barnes (Eds.), A Companion to Economic Geography, Blackwell, Oxford, 2000, pp. 77–94.
[45] E.L. Mclean, A. Becker, Decision makers' barriers to climate and extreme weather adaptation: a study of North Atlantic high- and medium-use seaports, Sustain. Sci. 11 (2019) 835–847.
[46] S. Messner, A. Becker, A.K.Y. Ng, Port adaptation for climate change: The roles of stakeholders and the planning process, in: A.K.Y. Ng, A. Becker, S. Cahoon, S. L. Chen, P. Earl, Z. Yang (Eds.), Climate Change and Adaptation Planning for Ports, Routledge, Abingdon, 2016, pp. 9–23.
[47] J. Nalau, B. Verrall, Mapping the evolution and current trends in climate change adaptation science, Clim. Risk Manag. 19 (2018) 10–18.
[48] A.K.Y. Ng, A. Becker, S. Cahoon, S.L. Chen, P. Earl, Z. Yang, Climate Change and Adaptation Planning for Ports, Routledge, Abingdon, 2016.
[49] A.K.Y. Ng, J.J. Liu, Port-Focal Logistics and Global Supply Chains, Palgrave Macmillan, Basingstoke, 2014.
[50] A.K.Y. Ng, J. Monios, H. Zhang, Climate adaptation management and institutional erosion: insights from a major Canadian port, J. Environ. Plan. Manag. 62 (4) (2019) 586–610.
[51] A.K.Y. Ng, A.A. Pallis, Port Governance Reforms in Diversified Institutional Frameworks: Generic Solutions, Implementation Asymmetries, Environ. Plan. A 42 (9) (2010) 2147–2167.
[52] A.K.Y. Ng, T. Wang, Z. Yang, K.X. Li, C. Jiang, How is business adapting to climate change impacts appropriately? Some insight from the commercial port sector, J. Bus. Ethics 150 (4) (2018) 1029–1047.
[53] A.K.Y. Ng, H. Zhang, M. Afenyo, A. Becker, S. Cahoon, S.L. Chen, M. Esteben, C. Ferrari, Y.Y. Lau, P.T.W. Lee, J. Monios, A. Tei, Z. Yang, M. Acciaro, Port decision-maker perceptions on the effectiveness of climate adaptation actions, Coast. Manag. 46 (3) (2018) 148–175.
[54] G. Norcliffe, K. Bassett, T. Hoare, The emergence of postmodernism on the urban waterfront: geographical perspectives on changing relationships, J. Transp. Geogr. 4 (2) (1996) 123–134.
[55] D.C. North, Institutions, Institutional Change and Economic Performance, Cambridge University Press, Cambridge, 1990.
[56] T. Notteboom, P. de Langen, W. Jacobs, Institutional Plasticity and Path Dependence in Seaports: Interactions between Institutions, Port Governance Reforms and Port Authority Routines, J. Transp. Geogr. 27 (2013) 26–35.
[57] T. Notteboom, P. De Langen, W. Jacobs, Institutional plasticity and path dependence in seaports: interactions between institutions, port governance reforms and port authority routines, J. Transp. Geogr. 27 (2013) 26–35.
[58] Oppenheimer, M., Glavovic, B., Hinkel, J., van de Wal, R., Magnan, A., Abd-Elgawad, A., Cai, R., Cifuentes-Jara, M., DeConto, R., Ghosh, T., Hay, J., Isla, F., Marzeion, B., Meyssignac, B., & Sebesvari, Z. (2019). Sea level rise and implications for low-lying islands, coasts, and communities. In H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, & N. Weyer (Eds.), *IPCC special report on the ocean and cryosphere in a changing climate*.
[59] W. Osthorst, C. Manz, Types of Cluster Adaptation to Climate Change: Lessons from the Port and Logistics Sector of Northwest Germany, Marit. Policy Manag. 39 (2) (2012) 227–248.
[60] R. Panahi, A.K.Y. Ng, J. Pang, Climate change adaptation in the port industry: a complex of lingering research gaps and uncertainties, Transp. Policy 95 (2020) 10–29.
[61] U. Paulsson, Supply chain risk management, Supply Chain Risk: A Read. (2004) 79–96.
[62] A.M. Pettigrew, The character and significance of strategy process research, Strateg. Manag. J. 13 (S2) (1992) 5–16.
[63] P. Pierson, Increasing returns, path dependence, and the study of politics, Am. Political Sci. Rev. 94 (02) (2000) 251–267.
[64] M.C.P. Poo, Z. Yang, Optimising the resilience of shipping networks to climate vulnerability, Marit. Policy Manag. 51 (1) (2024) 15–34.
[65] M.C.-P. Poo, Z. Yang, D. Dimitriu, Z. Qu, Review on Seaport and Airport Adaptation to Climate Change: A Case on Sea Level Rise and Flooding, Mar. Technol. Soc. J. 52 (2018) 23–33.
[66] M.C.P. Poo, Z. Yang, D. Dimitriu, Z. Qu, Z. Jin, X. Feng, Climate change risk indicators (CCRI) for seaports in the United Kingdom, Ocean Coast. Manag. 205 (2021) 105580.
[67] B.L. Preston, R.M. Westaway, E.J. Yuen, Climate Adaptation Planning in Practice: An Evaluation of Adaptation Plans from Three Developed Nations, Mitig. Adapt. Strateg. Glob. Change 16 (4) (2011) 407–438.
[68] T. Sager, Neo-Liberal Urban Planning Policies: A Literature Survey 1990-2010, Prog. Plan. 76 (2011) (2011) 147–199.
[69] M. Schaeffer, W. Hare, S. Rahmstorf, M. Vermeerm, Long-Term Sea-Level Rise implied by 1.5 °C and 2 °C warming levels, Nat. Clim. Change 2 (2012) 867–870.
[70] P.M. Smudde, J.L. Courtright, A holistic approach to stakeholder management: A rhetorical foundation, Public Relat. Rev. 37 (2) (2011) 137–144.
[71] T.C. Smythe, The impacts of Hurricane on the Port of New York and New Jersey: Lessons learned for port recovery and resilience, in: K.Y. Adolf, A.B. Ng, Stephen Cahoon, Shu-Ling Chen, Paul Earl, Zaili Yang (Eds.), Climate Change and Adaptation Planning for Ports, Routledge, Oxon, OX & New York, 2015.
[72] R. Stacey, Emerging strategies for a chaotic environment, Long. Range Plan. 29 (2) (1996) 182–189.
[73] S. Steinmo, K. Thelen, F. Longstreth (Eds.), *Structuring politics: historical institutionalism in comparative analysis*, Cambridge University Press, 1992.
[74] S. Strambach, Path Dependency, Path Plasticity and the Co-Evolution of Institutions and Innovation: The German Business Software Industry, in: R. A. Boschma, R. Martin (Eds.), Handbook for Evolutionary Economic Geography, Edward Elgar, Cheltenham, 2010, pp. 406–431.
[75] O. Tang, S.N. Musa, Identifying risk issues and research advancements in supply chain risk management, Int. J. Prod. Econ. 133 (1) (2011) 25–34.
[76] UNECE, Climate Change Impacts on International Transport Networks. Working Paper, Working Party on Transport Trends and Economics, UNECE, Geneva, Switzerland, 2010.
[77] H. Van Driel, G. Devos, Path dependence in ports: The persistence of cooperative forms, Bus. Hist. Rev. 81 (04) (2007) 681–708.
[78] J. Vergne, R. Durand, The missing link between the theory and empirics of path dependence: conceptual clarification, testability issue, and methodological implications, J. Manag. Stud. 47 (2010) 736–759.
[79] S.M. Wagner, C. Bode, An empirical investigation into supply chain vulnerability, J. Purch. Supply Manag. 12 (6) (2006) 301–312.

[80] T. Wang, A.K.Y. Ng, Responding to the barriers in climate adaptation planning among transport systems: insights from the case of the port of Montreal, Int. J. Sustain. Transp. 16 (10) (2022) 942–956.
[81] T. Wang, M.C.P. Poo, A.K. Ng, Z. Yang, Adapting to the Impacts Posed by Climate Change: Applying the Climate Change Risk Indicator (CCRI) Framework in a Multi-Modal Transport System, Sustainability 15 (10) (2023) 8190.
[82] T. Wang, Z. Qu, Z. Yang, T. Nichol, G. Clarke, Y.E. Ge, Climate change research on transportation systems: Climate risks, adaptation and planning, Transp. Res. Part D: Transp. Environ. 88 (2020) 102553.
[83] T. Wang, Z. Qu, Z. Yang, T. Nichol, D. Dimitriu, G. Clarke, E. Ge, Climate Change Research on Transportation Systems: Climate Risks, Adaptation and Planning, Transp. Res. Part D: Transp. Environ. 88 (2020) 202553.
[84] T. Wang, S. Samsom, A.K.Y. Ng, P. Earl, Climate change and adaptation of remote ports and supply chains in Manitoba, Canada, ISBN: 978-1-31-575681-3, in: A.K. Y. Ng, A. Becker, S. Cahoon, S.L. Chen, P. Earl, Z. Yang (Eds.), Climate Change and Adaptation Planning for Ports, Routledge, London, 2016.
[85] M. Weber, in: G. Roth, C. Wttich (Eds.), Economy and Society, University of California Press, Berkeley, CA, 1922, 1978.
[86] S.M. Wheeler, State and Municipal Climate Change Plans: The First Generation, J. Am. Plan. Assoc. 74 (4) (2008) 481–496.
[87] S.M. Wheeler, J. Randolph, J.B. London, Planning and Climate Change: An Emerging Research Agenda, Prog. Plan. 72 (2009) 210–222.
[88] Y. Xiao, X. Fu, A.K.Y. Ng, A. Zhang, Port investments on coastal and marine disasters prevention: economic modeling and implications, Transp. Res. Part B: Methodol. 78 (2015) 202–221.
[89] Z. Yang, A.K.Y. Ng, P.T.W. Lee, T. Wang, V. Sanchez Rodrigues, S. Pettit, I. Harris, D. Zhang, Y.Y. Lau, Risk and cost evaluation of port adaptation measures to climate change impacts, Transp. Res. Part D: Transp. Environ. 61 (2018) 444–458.
[90] G.A. Zsidisin, A grounded definition of supply risk, J. Purch. Supply Manag. 9 (5) (2003) 217–224.
[91] G.A. Zsidisin, S.A. Melnyk, G.L. Ragatz, An institutional theory perspective of business continuity planning for purchasing and supply management, Int. J. Prod. Res. 43 (16) (2005) 3401–3420.