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Climate change, natural disasters and adaptation investments: Inter- and intra-port competition and cooperation

Kun Wang[a,*], Anming Zhang[b]

[a] School of International Trade and Economics, University of International Business and Economics
[b] Sauder School of Business, The University of British Columbia, 2053 Main Mall, Vancouver, BC, Canada

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ABSTRACT

This paper investigates disaster adaptation investments made by two ports competing for shippers in a common hinterland. Each port is a landlord type, consisting of a port authority and a terminal operator that both maximize profits. The probability of a natural disaster, which is related to climate change, is ambiguous at the start of an adaptation investment (Knightian uncertainty), but will be known after the lengthy investment. We examine the impacts of such Knightian uncertainty, inter-port and intra-port competition and cooperation on the port adaptation investments. We find that a high expectation of the disaster occurrence probability encourages port adaptation, while a high variance of the disaster occurrence probability discourages port adaptation. Furthermore, inter-port competition results in more adaptation investments (the “competition effect”), whereas within a port there is free riding on adaptation between the port authority and the terminal operator (the “free-riding effect”). We further extend our analysis to public port authorities that maximize social welfare, and find that the competition effect on port adaptation still exists but the free-riding effect is no longer present. As a robustness check, a Poisson jump process is also used to model disaster occurrence at the operation stage. We find, with this Poisson assumption, the effects of Knightian uncertainty on port adaptation still hold.

1. Introduction

The past decade has witnessed more frequent extreme weather events and natural disasters around the world, with increasing economic and social costs. The examples include hurricanes and storms in recent years (e.g., Sandy in 2012 and, most recently, Harvey in 2017, on the United States coastline). For instance, Harvey brought an estimated economic loss of $125 billion,[1] whereas Sandy caused an estimated $70.2 billion loss (the United States National Hurricane Center).[2] Scientific studies suggest that climate change may lead to an increase in both the occurrence and the strength of weather-related natural disasters in the near future (e.g., Keohane and Victor, 2010; Min et al., 2011; IPCC, 2013). According to Morgan Stanley research, of the top-ten most costly hurricanes hitting the United States (US) until 2015, eight occurred in this century.[3] Such increasing frequency and strength of hurricanes in North Atlantic Basin is due, at least in part, to global

* Corresponding author.
E-mail addresses: wqueenfox@gmail.com (K. Wang), anming.zhang@sauder.ubc.ca (A. Zhang).

[1] Unless specified otherwise, the dollar amount in this paper refers to US$.

[2] Please see the link for details: https://weather.com/storms/hurricane/news/2018-01-29-americas-costliest-hurricanes.

[3] The details about the top-ten hurricanes can be found at http://www.businessinsider.com/hurricane-irma-costliest-hurricanes-us-history-map-2017-9.

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warming and related temperature rise of the ocean (IPCC, 2013). The global warning largely increases the risk of coastal and marine natural disasters (in terms of frequency and intensity) around the world. By the end of this century the average sea level may be 0.75-0.80 meters higher than today's level (Schaeffer et al., 2012). Global warming and associated sea-level rise (SLR) can bring about more frequent and intense wind, freshet flooding and complex tide waves (IPCC, 2013; OECD, 2016).

Seaports are highly vulnerable to coastal and marine natural disasters, and are exposed to climate hazards. For example, Nicholls et al. (2008) assessed the exposure to flooding for 136 large port cities around the globe. Stenek et al. (2011) and Scott et al. (2013) gauged the vulnerability for port system sub-components to climate change, including navigation, berthing, material handling, vehicle movement, goods storage and transportation. The increasing risk of natural disasters to seaports may trigger substantial social and economic loss and, in particular, lead to shifts in freight transport and passenger flow (Koetse and Rietveld, 2009). Many ports play a critical role in global supply chains, so that any significant loss or degradation of service due to these disasters would have significant knock-on effects on global supply chain performance (OECD, 2016).

Unlike the rich literature on environmental effects of transportation (especially the mitigation of transport sector to climate change; see, e.g., Zhang et al., 2004; Wang et al., 2015), there is a lack of theoretical research on adaptation of maritime transport to climate change-related disasters.[4] One exception is Xiao et al. (2015) who modeled seaport adaptation investments by both port authority and terminal operator under the uncertainty of disaster occurrence. They found that there is a free-riding effect of adaptation efforts for the port authority and terminal operator, and that information about the disaster occurrence is essential for the optimal timing of adaptation investments (the "invest now or later" question). It is noted that Xiao et al. (2015) considered port adaptation of a single port and so they did not consider inter-port competition.[5] They further treated port demand and pricing being exogenous to adaptation investments. Nevertheless, port adaptation and resilience to natural disaster can affect a port's competitiveness vs. neighboring ports. For instance, port disruption can cause serious reputational and direct economic losses on shippers (Zhang and Lam, 2015), leading to their switching to a better adapted port for services (Chang, 2000).[6] Therefore, an improved theoretical model on port adaptation need to endogenize the shipper's demand and port pricing decisions, and incorporate the inter-port competition as well.[7]

Furthermore, despite a rich theoretical literature on traffic demand uncertainty modeling,[8] uncertainty about climate change-related disasters and the associated costs have not been well modeled in existing maritime transport studies. Uncertainty regarding their occurrence and outcomes can be very high (IPCC, 2013; OECD, 2016), due to limited scientific knowledge and to forecast complexity. In contrast, traffic demand can be more accurately forecasted with the availability of rich historical traffic data and other economic and demographic variables. Therefore, to model uncertainty of climate change-related disasters, one needs to account for the large ambiguity at the adaptation planning and investment stage, noting that adaptation projects usually are lengthy in duration and very costly. Xiao et al. (2015) modeled the disaster uncertainty in a two-period setting, assuming a uniformly distributed disaster occurrence probability in the first period but, with information learning, a more accurate (a more narrowly-bounded uniform distribution) probability in the second period. There is thus an option value in delaying investment, owing to better information about the disaster occurrence probability. However, this assumption of uniformly-distributed disaster occurrence probability could be restrictive. In this paper, we propose a model allowing a general distribution of the disaster occurrence probability, which can capture the "ambiguity" notion of disaster uncertainty that is absent in Xiao et al. (2015).

Taken together, the present paper contributes to existing literature by developing a more general analytical framework to analyze port adaptation to climate change-related disasters. More specifically, we model the climate change-related disaster occurrence probability to have Knightian uncertainty (Knight, 1921) at an early adaptation investment stage when two ports make adaptation decisions. Knightian uncertainty refers to ambiguity in which a decision maker must make decisions when the relevant probabilities are unknown. This is used to capture the fact that the probability of disaster occurrence is very

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[4] There are a number of studies on post-disaster relief, and transport and logistics system resilience (e.g., Chen and Yu, 2016; Huang et al., 2013; Rawls and Turnquist, 2010; Sheu, 2014), but studies on adaptation strategies are relatively few. Further, the adaptation studies mainly adopt engineering approaches to an analysis of optimal cargo flows so as to enhance resilience of the supply chain or network. Economic-based strategy and policy analysis is rare, however.

[5] Recently, port competition and cooperation were also analyzed in the context of disaster prevention by Liu et al. (2018b), in which the ports can be either substitutes or complements with each other. They focused on the case of mitigation rather than adaptation, however.

[6] For example, Chang (2000) empirically studied the impact of the 1995 Great Hanshin earthquake on the port of Kobe (Japan), which was shut down post the disaster and only recovered after two years. She found that due to the earthquake damage, the Kobe port lost most of transshipment cargo to competing Asian ports, in both the short- and long-term.

[7] Theoretical analyses on port competition and the interplays between ports and their hinterlands are emerging. Wan et al. (2018) reviewed recent theoretical studies in the area, and found that these studies mainly focus on the port and hinterland capacity investments, and on port congestion pricing (De Borger et al., 2008; Zhang, 2008; De Borger and Proost, 2011; Luo et al., 2012; Wan and Zhang, 2013; Yuen et al., 2008). Some recent studies discussed the emission control of marine transport, such as Homsombat et al. (2013), Wang et al. (2015), Sheng et al. (2017) and Dai et al. (2018). However, none of these papers have considered port adaptation to climate-change risks.

[8] See, for example, the studies by Kraus (1982), D'Ouville and McDonald (1990), Proost and Van der Loo (2010), and Xiao et al. (2013). Kraus (1982) considered highway pricing and capacity choice under demand uncertainty, and found that both capacity and price are greater than those under an expected value of demand. D'Ouville and McDonald (1990) also studied the optimal capacity and toll of urban highways under demand uncertainty, and found that a social planner who simultaneously chooses the capacity and congestion toll to maximize the expected welfare will choose a larger capacity relative to the mean level of road use. Proost and Van der Loo (2010) examined capacity choice by modeling a social planner's decision on transport infrastructure capacity when the future demand can be either high or low, with different tolls being set for each case to maximize welfare. Xiao et al. (2013) analyzed the effects of demand uncertainty on airport capacity choices.