ABSTRACT

Title of Dissertation: SITUATIONAL PERSPECTIVE OF MARITIME PIRACY

Bo Jiang, Doctorate of Philosophy, 2019

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The emergence of maritime piracy has caused much concerns among various dimensions of our society. However, with few exceptions prior research has been hampered by a lack of theoretical underpinning and access to the most appropriate statistical methods. While there are nuances of piracy that can be considered quite unique, in general it can be situated within a broader framework of offending based on outcomes that seemingly share many of the same qualities. My dissertation attempts to improve our understanding of the crime by testing three core tenets of situational perspectives in the context of piracy. Three research questions motivated by LaFree and Birbeck (1991)'s conceptualization of a situation are examined – 1) To what extent does the study of maritime piracy support the central tenets of environmental criminology and crime and harm concentration at places; 2) How do offender motivation, target suitability and the absence of capable guardians and their convergence impact the instantaneous risk of piracy in South East Asia; and 3) To what extent do economic conditions of fishermen impact the instantaneous risk of piracy in East Africa and South East Asia. I rely on the IMO-GISIS database from 1995 to 2014, as well as auxiliary data from various organizations to tackle these questions. First, exploiting spatial econometrics methods, I find that there is statistically significant spatiotemporal patterns of concentration of hot and harm spots. Second, results from survival analyses indicate that the hazard ratios of the measures of high motivation, absence of capable guardians, suitable targets and their convergence are greater than 1 and significant in both the Malacca Strait and South China Sea. The series of robustness tests based on both frequentist and Bayesian statistics provide similar conclusions. Third, using a two-stage semiparametric approach, I find that there is statistically significant evidence to show that economic conditions of the fisherman-pirate adversely impact the instantaneous risk of ships being attacked in East Africa and the Malacca Strait and South China Sea. A robustness check based on an alternative specification supports the finding. I conclude with the implications of the research for theory, social policy and future research.

SITUATIONAL PERSPECTIVES OF MARITIME PIRACY

by

Bo Jiang

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Distinguished Professor Lawrence Sherman

Dedication

I dedicate this work to the memories of my grandparents who encouraged me to pursue my dreams. Interest in criminology and the criminal justice system, for me, is directly influenced by them although they were unable to see my graduation.

Acknowledgements

The Beginning

From 2004 to 2013, I gained valuable research experience while studying and working at the National University of Singapore under the mentorship of Professors Anthony Chin, Toh Mun Heng, Kim Sun Bae, and Lim Chin. They introduced me to the economics behind maritime piracy and human trafficking, two types of crimes which were prevalent in Singapore and its surrounding region. In the 2000s', good research on these topics was hard to come by and nothing seemed to accurately reflect the causes and consequences of the two crimes. There were many research available and they were all lacking in one quality or another. There had to be something better. My mentors challenged me to perform research on these topics from an economic perspective. As a hobby, I thoroughly enjoyed reading up on the criminological perspectives of maritime piracy during my spare time because they seemingly share many of the same qualities as the economics of crime. I owe an unending debt of gratitude to them for kindling the passion in the study of maritime piracy, and their relentlessly support along the way. What started off as a hobbyist project eventually mothed into a full dissertation.

My Formal Introduction to Criminology

During my initial research on the rational-choice theory, I came across the works by Professors Laura Dugan and Gary LaFree. Their research was so enlightening that I aspired to emulate their model to study maritime piracy. I was truly convinced by their expertise. I first met Professor Laura Dugan at the University of Maryland in 2011 when I came to consult her unofficially. She helped me without reserve even though I was just visiting. Her kindness is deeply appreciated and I respect her dedication to the field. Two years later, I officially became a doctoral student at Maryland under the mentorship of Professors Dugan and LaFree. Their meticulous guidance during the last eight years have been indispensable to this work.

Using Dr. Dugan's method, I performed a fun project out of my spare time entitled "Maritime Piracy in Malacca Strait and South China Sea: Testing the Prevention, Deterrence, and Reactance Models" and sent it to *Criminology* (manuscript #2013-046) without any pressure to publish. Although the article was rejected, I was very grateful to the 14 pages of constructive comments from the co-editor, Dr. Eric Baumer, and three anonymous reviewers. It turned out that this casual submission had a turning point effect on my life trajectory.

Perhaps more importantly, the thought of pursuing a PhD in Criminology in the research area of maritime piracy would have never cross my mind without the encouragements from Dr. Baumer. Specifically, he wrote in the referee report that "…All of the reviewers saw significant value in studying maritime piracy and considered this to be a potentially exciting addition to the range of substantive areas

represented in the journal. Additionally, the reviewers judged the paper to possess many of the ingredients needed to make a solid theoretical and empirical contribution… I found the topic to be refreshing and considered many elements of the study to hold significant potential for advancing understanding of trends in piracy and related outcomes." Additionally, he gave me several instructive suggestions to broaden the appeal of my work within mainstream Criminology. I was very motivated and that was probably when I became a criminology enthusiast who is determined to pursue a PhD. To this end, I cannot thank him enough for inspiring my continued pursuit of maritime piracy.

The Dissertation

This dissertation involves a great deal a criminological theories and I came to the United States with only very modest knowledge of what Criminology entails. I was first introduced to the field by Professors Freda Adler and James Finkenauer at the University of Pennsylvania. They not only offered me insightful guidance at all stages of writing this research but also provided endless material support for my family in the process of pursuing my studies in the United States even till this day. Without their direction, settling in the field would have been much more challenging. To fulfil my dream of obtaining a PhD in Criminology, they introduced me to Professor Gary LaFree and I truly could not ask for a better mentor.

During the last six years, I was fortunately enough to have the opportunity to be the apprentice of Professor Gary LaFree, who painstakingly molded me into a fledging criminologist. In particular, I benefitted tremendously from his expertise in situational perspectives. This research would not have been possible without the numerous consultation sessions and back-and-forth editing. The apprentice-master relationship is truly unique and would last a lifetime. I am truly indebted to his magnanimity.
I would especially like to thank Emeritus Professor Denise Gottfredson for her many hours of guiding me through the revision of the original article rejected by *Criminology,* which formed the backbone of this dissertation. Given her recent retirement, Emeritus Professor Gottfredson is under no moral obligation whatsoever to serve on my committee. I owe her an incredible debt for her continued support.
Professor Lawrence Sherman provided numerous instructive suggestions and extended ideas that opened up new perspectives for me. Many aspects of the first research question could not be materialized without his valuable guidance. His generosity in sharing his expertise in the Cambridge Crime Harm Index is graciously acknowledged.

I am grateful to my external committee member, Associate Professor David Cunningham. He carefully and patiently read the draft of my proposal and shared important ideas and profound insights from the Government and Politics perspective. His instructive suggestions have been central to this research.
I truly appreciate the financial aid offered by START during my studies at Maryland. Without the graduate research assistant appointment and full-time summer funding, the completion of my research endeavor would least likely to take place. I also

acknowledge the IT team at START for providing me an advanced computer server and ArcGIS software licensing to tackle the demanding needs of the geographical and statistical models employed in this research. Thank you to all my colleagues at START, especially Bill Brandiff, William Kammerer, Erin Miller, Michael Distler and Brandon Behlendorf for your camaraderie all these years. Last but not least, my heartfelt thanks goes to Lauren Grant and Charlene Werner for their administrative backing of my studies at Maryland.

Given that there are just so many dedicated and warm-hearted folks who had helped to make this dissertation possible, I hesitate to conclude this short acknowledgment. However, due to practical constraint, I have to reluctantly end here. My sincere apologies to those whom I did not address. Please rest assure that your kindness will not be forgotten.

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Chapter 1: Introduction

The study of the causes and consequences of maritime piracy is nascent in the field of Criminology. This neglect is unwarranted given that it has been plaguing the safety of sailors, ships and their cargos since at least the 14th century BC (Thomas, 2013). Notwithstanding, this form of law-breaking could clearly benefit from what our field has to offer. While there are nuances of piracy that can be considered quite unique, in general it can be situated within a broader framework of offending. Even though there are limited systematic studies of piracy in the empirical literature, there is a long history of criminological research on outcomes that seemingly share many of the same qualities. Some aspects of piracy seem relevant to organized crime, gang and subculture, while other elements parallel behaviors such as robbery, aggravated theft, kidnapping and hijacking.

Sutherland and Cressey (1978:3) defined criminology as “the study of the breaking of laws and reactions to the breaking of laws” and piracy is clearly encompassed in their definition. Indeed, Adler (1996) identified sea piracy as one of the 19 areas of transnational crimes. Despite our knowledge about the etiology and repercussion of air- and land-based transnational crimes (Albanese, 2011), we know relatively little about those that are perpetuated in the oceans. In my dissertation, I endeavor to integrate the topic sufficiently with existing criminological literature to make the study of piracy part of mainstream criminology. Here, I lay the foundation by providing the definition of piracy applied, a broad overview of the distribution of pirate attacks worldwide, the extent and impact of the crime on the social, economic, politics and geopolitics fronts, before launching into a review of theoretical perspectives in the next Chapter.

According to the 1982 United Nations Convention on the Law of the Sea Article 101, maritime piracy is defined as "the following acts: (a) any illegal acts of violence or detention, or any act of depredation, committed for private ends by the crew or the passengers of a private ship or a private aircraft, and directed: (i) on the high seas, against another ship or aircraft, or against persons or property on board such ship or aircraft; (ii) against a ship, aircraft, persons or property in a place outside the jurisdiction of any State; (b) any act of voluntary participation in the operation of a ship or of an aircraft with knowledge of facts making it a pirate ship or aircraft; (c) any act of inciting or of intentionally facilitating an act described in subparagraph (a) or (b)." (UNCLOS, 1982). Based on "The Convention" of 1982, acts of piracy and armed robbery at sea had been subjected to 18 UN Security Council resolutions from 2008 to 2017[i].

The emergence of maritime piracy has caused a great deal of concerns among various dimensions of our society. On the social front, during the past decade alone, *The New York Times* published more than 300 articles related to the topic "piracy at sea". Even a film titled "*Captain Phillips*" was released in 2013, motivated by the true story of the hijacking of the American-flag container ship *Maersk Alabama* during 2009 in the Horn of Africa. These and other media reports of pirates attacking vessels using violent means and demanding exorbitant ransoms for the exchange of hijacked vessels and the safe release of hostages on board have increasingly captured the world's attention. During the 2005 – 2011 period, a World Bank report estimated that around 100 seafarers have died at the hands of Somali pirates alone, and around 3,741 seafarers from 125 countries were kidnapped (World Bank, 2013). As the so-called piracy 'business-model' became more mature and sophisticated, the ransom payment and length of negotiation grew dramatically. In 2008, one research estimated that the ransom paid amounted to approximately \$60 million, and it grew fourfold to around \$238 million within three years (Payne, 2010). In terms of the average ransom paid, the same research indicated that this figure stood at around \$5.4 million in 2010, compared to just \$150,000 in 2005 (Payne, 2010). Another report estimated that the aggregate ransom costs (actual amount paid, cost of negotiation, delivery of cash by private helicopter/plane and other costs related to the psychological trauma of the victims and ship repairs) during the 2009 – 2010 period came in at around \$830 million (Bowden, 2010). The duration of ransom negotiation lengthened with increasing random demands. For seafarers, the average length of captivity is around 3 – 4 months in 2010, with some for as long as three years. For vessels, they were held on average for 100 – 150 days.

Unsurprised, oceanography and climate research have also been undermined due to the increasing risk of pirate attacks. Smith et al. (2011) explained that merchant vessels that carry instruments which measure and record weather conditions were forced to alter their navigation tracks. As a result, piracy poses a serious threat to the monthly wind analysis. Reducing the number of surface wind observations meant that scientists are unable to accurately forecast the spatial extent and strength of the Somali jet. Moreover, other crucial measurements such as wave-heights from buoy observations near the Somali coast cannot safely be taken. The discontinuity in the long-term record of these measurement necessary for studying the multidecadal variations in monsoon cycles meant that fishermen and ship owners could not obtain reliable information from marine forecasts.

On the economic front, the recent resurgence of piracy is in part due to the forces of globalization and free trade, which exponentially increased the movement of merchant vessels across the oceans. The International Maritime Organization (IMO) noted that: "Maritime transport is essential to the world's economy as over 90 percent of the world's trade is carried by sea and it is, by far, the most cost-effective way to move en masse goods and raw materials around the world." Moreover, the United States Energy Information Administration reported that approximately 59 million barrels of refined petroleum products and crude oils, or 61 percent of the world total, were transported by sea as of 2015 (United States Energy Information Administration, 2015). A recent example of successful hijacking of an oil tanker is the *MV Sirius Star,* which at the time of invasion was carrying at least $100 million worth of crude oil and itself worth approximately $150 million, according to a 2009 report from *The Guardian*[ii].

Jeopardizing global economic interdependence, various estimates suggest that the economic cost of piracy to be approximately $13 to $16 billion dollars in 2004, and $7 to $12 billion dollars in 2010 (Bowden, 2010; Liss, 2011; Fluckiger and Ludwig, 2015). The ransom paid for the hijacking of vessels and crew members have also skyrocketed in the last decade. For instance, one source suggests that the "average ransom paid had increased from $150,000 in 2005 to $5.4 million five years later" (Pristrom, 2011:1)[iii]. Bowden (2010) estimated that ransom related costs amounted to a combined value of around $830 million from 2009 to 2010. The additional shipping costs constitute the lion's share of the overall maritime piracy spending. For instance, the United States Maritime Administration and the United States Department of Transportation performed an economic analysis of avoiding the Horn of Africa region by rerouting vessels via the

Cape of Good Hope. The report showed that the alternative strategy reduces the delivery capacity of ships as it adds 2,700 miles to the voyage or about $350,000 additional fuel and wages cost per voyage[iv]. If piracy continues to be problematic and ships decide to reroute and bypass the Gulf of Aden, the former Commander of Combined Task Force 151 claimed that oil prices in the United States could experience a spike (Mcknight, 2012). To meet the time-sensitive demand of the global value chain and in particular the just-in-time manufacturing industries, rerouting a trip from Europe to the Far East would incur an additional $15 million in chartering additional ships to maintain the scheduled service and another $75 million in added fuel cost annually. As a result of the heightened risk of piracy from 2008 onwards, the additional insurance premium for vessels passing through the high risk areas is around $150,000 per voyage (Mudric, 2011; Bowden, 2010).

For enhanced protective measures, the Best Management Practices 4 of the International Maritime Bureau recommends the use of private security company armed guards charging approximately $21,000 per day or $100,000 per voyage for a three man armed detail (Ghosh, 2014). The Yemini Navy working in conjunction with a UK private security firm also provides paid escort to ships transiting the Gulf of Aden for about $55,000 per voyage (Ghosh, 2014). The Private Security Company (PSC) is a highly profitable industry with an estimated annual income of at least $100 billion (Straub, 2013).

To recoup these costs, several major shipping companies are imposing a piracy surcharge of around $100 per container, or $200,000 for a typical medium size container ship. Combined international and regional efforts to combat piracy at the major chokepoints or 'activity nodes' of international shipping consumed a great deal of wherewithal. In the Horn of Africa, some of these efforts include the Combined Task Force 151, NATO's Operation Ocean Shield and the European Union's Operation Atlanta. One estimate suggests that in the Gulf of Aden, the US Navy's cost of operating a single vessel per day is more than $80,000. Approximately $2 billion annually is spent on combined international naval operations to combat piracy (Bowden, 2010).

The political repercussions of piracy are dire. In response to the *Maersk Alabama* hijacking incident, President Obama signed Executive Order 13536 stating that "…acts of piracy and armed robbery at sea off the coast of Somalia… constitute an unusual and extraordinary threat to the national security and foreign policy of the United States", and the President "declared a national emergency to deal with that threat" (Obama, 2010). The US government advised all merchant ships flying its flag of convenience to hire private security guards. On the other hand, the use of armed private security company guards on commercial vessels has caused diplomatic fallout between states due to conflict over jurisdictions; heightened tensions among members of the UN[v]; NATO[vi]; and the European Union (Cusumano and Ruzza, 2018). During an interview, the pioneering US Commander of Task Force 151 also expressed concerns for the exponential growth of the private securities industry and the hiring of (untrained) private security guards who must "follow the same standards the militaries are following" and not "just fire on anybody without concern for human rights" (McKnight, 2012:1)[vii].

Moreover, the arrest and trial of (suspected) pirates are fraught with implementation difficulties. The international judicial relations between Somalia, Kenya, Seychelles and Western countries were strained because they are not always open to the possibility of charging pirates in their courts, including those who attacked Westerners (Johnson, 2010; Shortland and Vothknecht, 2011). In Kenya, interviews conducted by Shortland and Vothknecht (2011) showed that trials of pirates were often delayed as a result of a massive backlog of cases. In Seychelles, around 20 percent of prisoners in 2012 was Somali pirates[viii] (Finn, 2013). Of the few that did materialize in Kenya, 24 out of 59 collapsed and resulted in the release of the pirates. There are also concerns expressed over the maltreatment of pirate waiting for trial, as interviews by Shortland and Vothknecht (2011) showed. Consequently, pirates who attacked Westerners were increasingly trialed in Western courts. Somali pirates who hijacked French registered ships were detained and flown back to France to stand trial (*Ali Samatar and Others v. France*[ix] and *Hassan and Others v. France*[x]). The pirates appealed to the European Court of Human Rights, which held unanimously that the French authorities violated the European Convention of Human Rights. The deprivation of the human rights of pirates as a result of frustrated governments was contentiously debated (Dubner and Otero, 2016).

Last, piracy has also sparked serious geopolitics worries around the world, particularly for East Africa. For instance, the Ukrainian cargo ship *MV Faina* carrying 33 Soviet T72 battle tanks and a range of other heavy weapons and ammunitions was hijacked by a pact of 50 Somali pirates in 2008. A spokesperson for the US Navy's Fifth Fleet expressed deep concerns that the arms could possibly end up in the hands of Islamist insurgents based on land, such as terrorist organizations *Al Shabab* in Somalia and *Al Qaeda* in Yemen[xi], who were keen to replicate the LTTE Sea Tigers by recruiting ex-pirates to create their own maritime divisions (Ghosh, 2014). In South East Asia, Chalk (2000) and Ong-Webb (2006) opined that pirates may cooperate with, or provide some assistance to terrorist organizations. The tanker *Dewi Madrim* was hijacked by pirates in Indonesia and no ransom was demanded for the release of the hostages is one such case in point.

1.1 Nature of Piracy in the South China Sea and Gulf of Aden

An examination of the temporal trends in the database created by this dissertation revealed that worldwide pirate attacks could be decomposed into two main waves with each lasting about a decade. The first wave was tightly coupled to the trend in pirate attacks in South China Sea, and the genesis of the second wave of worldwide pirate attacks coincided with the upward trajectory of attack pattern in East Africa. Before discussing these the salient features of these patterns in the results chapter, I first briefly introduce the two regions covered in the study.

The International Hydrographic Organization (IHO) defined the limits of the South China Sea (*Nan Hai*) as: "…bounded on the north by China, on the east by the Philippine islands, on the south by the Indo, and on the west by the Malay Peninsula and Vietnam…. ; encompassing an area of around 3.5 million square kilometers, it contains more than 230 scattered islets, reefs, and shoals and is subdivided into four sub-archipelagos: The Spratly Islands, the Macclesfield Islands, the Paracel Islands and Pratas Islands." (IHO, 1953:30-31). The South China Sea is connected to the Indian Ocean through the Malacca Strait - 885 km long, reaches a width of 400 km in the north, 16 km in the south; and is 2.7 km at its narrowest point. Territorial disputes over the South China Sea by the littoral countries have made it one of the world's most dangerous points of conflict and created challenging problems in terms of maritime security and management. The International Chamber of Shipping estimated that since 2000, more than 70,000 merchant ships (weighing at least 300 gross tons) carrying half of the world's trade transit the South China Sea region every year.

The Gulf of Aden is a strategic shipping route linking the Indian Ocean and the Mediterranean Sea. Serving as the gateway for trade carried by the sea between Asia and Europe, more than 80 percent of trade transiting the Gulf is with Europe. For the last decade, the value of Asia-Europe trade increased from 900,000 million Euro to more than 1,400,000 million Euro (EuroStat, 2017). Another strategic importance of the Gulf is that geographically it is the chokepoint for Persian Gulf export of petroleum toward Europe, the United States and Asia, with an estimated 3.8 million barrel per day of petroleum products and crude oil passing through the waterway in 2013 (Birchnell, Savitzky and Urry 2015). The authors stated that the number of vessels transiting the Gulf averaged 20,000 annually during the late 2000s. Of these ships, approximately 1 percent were invaded at the height of piracy from 2009 to 2011, according to my estimation. The emergence of economically lucrative preys travelling close to land at low speed, combined with hardships experienced on land near the major shipping lanes and dearth of capable guardians, make piracy tempting in these regions. Naturally under these conditions one would reasonably expect that the risk of piracy is not unpredictable.

1.2 Limitations of Past Research

Piracy is clearly a form of law breaking that could benefit much from what criminology has to offer. Unfortunately, in spite of the social, economic, political and geopolitics repercussions of the crime, the topic has been largely ignored by criminologists, with few exceptions. For the most part, criminologists have adopted the qualitative approach in their study of piracy, focusing mainly on the historical context

(Mueller and Adler, 1985; Eklof, 2006; Elleman, Forbes and Rosenberg, 2010); structural influences on the incidences of piracy, especially the impact of failed or fragile states and economic hardships (Vagg, 1995; Johnson and Valencia, 2005; Young, 2007; Jablonski and Oliver, 2013; Daxeeker and Prins, 2013), the connection between organized crime, terrorists, guerrilla movements and maritime piracy (Chalk, 2000; Ong-Webb, 2006) and responses to piracy (Liss, 2010; Beckman, 2012). Many of the authors conducted field work through interviews with the pirates, officers from the enforcement agencies, crews who were victims of piracy and the village chief where the pirates originate. Although such research provides a qualitatively revealing and comprehensive discourse on the characteristics of maritime piracy, it does not offer systematic statistical tests of hypotheses. After an extensive literature review, it became clear that the bulk of the studies that applied criminological theories to piracy was performed within the last five years. Given the spatial and temporal clustering of piracy attacks, criminology scholars have recently applied principals from environmental criminology, the routine activities perspective, and rational-choice theory and the crime prevention through environmental design perspective to study that variability. However, prior studies that tested these theories were fraud with conceptual and methodological limitations which I will explain in the next chapter.

1.3 Contributions of My Dissertation and Roadmap

To confront these challenges, I rely on LaFree and Birbeck (1991)'s conceptualization of a situation, which links the *behavior* of a pirate, or a group of pirates, as a response to changes in the *environmental structure*. Three specific research questions that are founded based upon this overarching theoretical conceptualization will be examined in my research. In the next chapter, I first clarify the notions "behavior" and "environmental structure" and their intricate linkage, before applying these concepts to the context of maritime piracy.

Based on LaFree and Birbeck (1991)'s conceptualization of a situation, in this dissertation I formulate the following three main research questions:

R1) To what extent does environmental criminology, crime pattern theory and crime concentration at places improve our understanding of maritime piracy?

R2) How do offender motivation, target suitability and the absence of capable guardians and their convergence impact the instantaneous risk of piracy in South East Asia?

R3) To what extent do economic conditions of fishermen impact the instantaneous risk of piracy in East Africa and South East Asia?

To address these research agendas, I rely on three theoretical perspectives that are core components of situational theories. They are environmental criminology, routine activities perspective, and the rational-choice theory, respectively.

The remainder of the dissertation is set up as follows. Chapter 2 consists of two parts. First, I situate piracy within the broader framework of offending by drawing upon several theories that explain the situation in which piracy occurs at a given time and place. These include crime and harm concentrations at places, the routine activities perspective and the rational-choice theory. Second, prior research testing these perspectives are critically assessed, delineating their relative strengths and weaknesses and the ways in which they could be improved. I then explain how the case of maritime piracy could be conceptualized and tested for each of the perspectives. In Chapter 3, I identify the data that have been collected for this research and make clear how the measures used to operationalize the theoretical constructs are derived. Also, I provide a detailed description of the analytic strategies used for the three research questions. The results and their statistical interpretation for the modeling approaches employed to test the three research questions is presented in Chapter 4. In the final chapter, I first seek to discuss the substantive interpretation of my statistical findings. Next, I elucidate the theoretical and methodological value-added of my contributions for the three components of situational perspectives. The policy implications, limitations, and a plan for future research are presented before I conclude the dissertation.

Chapter 2: Theoretical Perspectives, Prior Research and Hypotheses

Recently, criminologists are becoming increasingly mindful of the application of mainstream criminological theories to conceptualize the study of maritime piracy. For instance, in the latest edition of *The Oxford Handbook of Environmental Criminology,* Townsley (2018) demonstrated the application of mainstream criminological theories to the niche topic of maritime piracy. His chapter showcased that salient features of the crime are no different than ordinary crimes and it can be conceptualized using the jargons of environmental criminology. Likewise, Linley (2015)'s doctorate dissertation linked key insights from environmental and developmental criminology to explain the onset, persistence and desistence of piracy in Somalia from a qualitative perspective. In spite of these recent attempts to bridge the theoretical divide, the application of criminological theories to the context of maritime piracy still remains uncommon and rudimentary. To confront this limitation, I endeavor to accomplish three goals in this chapter: 1) Review the evidence related to the criminological theories that I plan to apply to the study of maritime piracy; 2) Situate maritime piracy in the context of these criminological theories; and 3) Set up the stage for inductive exploration of the first research question R1 and deductive hypothesis testing of the second and third research questions R2 and R3.

I kick off this chapter by reviewing three situational theories of crime – environmental criminology, routine activities perspective and rational-choice theory – before launching into the application of each theory to my three research questions and finally setting up the hypotheses to be tested. It proceeds as follows. In section 2.1, I provide a broad overview of situational perspectives. Then in section 2.2, I perform a literature review of environmental criminology in the areas of crime and harm concentrations at places. In section 2.3, I discuss the strengths and weakness of prior studies that applied environmental criminology perspectives to maritime piracy. Finally, I attempt to apply the principals of environmental criminology to the context of maritime piracy using an inductive approach in section 2.4.

For the second research question R2, to address the effects of offender motivation, target suitability and the absence of capable guardians and their convergence on piracy, I review the literature on the routine activities perspective in section 2.5. Next, I critically evaluate prior research which tested it in the context of piracy in section 2.6. Finally, in section 2.7 I set up Hypotheses 1 – 4 related to each of the three core components of the approach and their convergence effect, respectively,

For the third research question, I begin by reviewing the key concepts within rational-choice theory in section 2.8. In the next section, the case of how piracy is affected by economic conditions in Somalia is explained. In section 2.10, I attempt to summarize and critically evaluate the strand of research examining economic conditions and piracy. Hypothesis 5 is set up in section 2.11. 2.12 concludes the chapter.

2.1 Review of Situational Theories of Crime

In this section, I first set the stage by carefully outlining what situational theories entail generally. I then delve into specific notions of a situation and review prior studies that tested them within the realm of environmental criminology, and crime concentration at places in the subsequent sections.

One of the seminal articles that looked at the situational characteristics of crime is LaFree and Birbeck (1991). The authors traced the lineage of its development to psychologists Murray (1938) and Pervin (1978). The cornerstone of their definitions rest upon the fundamental assumption of a dynamic interaction between the individual and the environment in which he/she is embedded. A situation, therefore, links the behavior of an individual "as a response to the changes in the environment" (LaFree and Birbeck, 1991:75). They defined the term situation as: "the perceptive field of the individual at a given point in time" and the analysis of situation as "the search for regularities in relationships between behavior and situations" (p.75). Regarding the perceptions and motivations of potential offenders, they criticized opportunity theorists such as Felson and Cohen (1981), Cornish and Clarke (1986) and Cook (1986) for assuming that motivation is assumed to be constant. In their view, offender perception and motivation need not remain static in the routine-activity approach. According to the predictions of the symbolic interaction theory (Cooley, 1922; Mead, 1934), the meaning of specific situations are endowed by those actors involved. Studies in experimental and symbolic interaction focus on the role played by situations in stimulating offenders to engage in criminal behaviors by the actual or threat of the imposition of negative stimuli, or positive rewards. Along this line of reasoning, the interaction between the offender and the situation implies that motivation is dynamic and it varies with each characterization of the confronting situation. In turn, the extent to which motivation can be fulfilled relies on the opportunity.

After explaining that the study of the situation is not adequate as discussed earlier, LaFree and Birbeck also observed that the study of the situation in criminology is neglected. To help conquer these challenges, the authors studied the situational clustering of several types of personal contact crimes using victimization surveys in the US and Venezuela. There were substantial support for greater situational clustering for noncoercive criminal techniques and instrumental coercive crime. The nuance of the models also showed that female victims, lone victims, the young and the old are attractive targets for noncoercive crimes, and they tend to occur in outside and public locations during daytime. On the other hand, instrumental coercive crimes tend to target strangers with few others around.

Birbeck and LaFree (1993) performed a review of three lineage of research that examined the conceptualization of the situational contexts in crime and deviance. Based on Hirschi and Gottfredson (1986)'s distinction of crime and criminality, the authors argued that even though the former might appear to be a more appropriate crime explanation, the dearth of evidence is a result of the complexity involved in operationalizing key theoretical constructs and the modeling of the interaction between offenders and situations. This led to divergent and independent paths of theoretical development along the domains of experimental studies, symbolic interactionist studies and opportunity theories, even though underlying them is the common theme of situational dynamics. Central to the current study are opportunity theories, in which could be partitioned into theories of situational selection and victimization. In the former case, the authors explained that while it is prevalent among offenders, planning appears to be variable. Also, there is a great deal of variability in the type and selection of situations depending on offender and crime type. In the latter case, they noted that based on the studies of situational selection, the degree of support for the patterns of victimization remains relatively limited. Given that motivation is contingent upon opportunity, the authors summarized that it then becomes “a plan of action involving a specific configuration of situational variables” (p.131). In this sense, the situational perspective enhances our understanding of criminality through viewing offenders as situated actors.

Congruent with the vision of Birbeck and LaFree (1993), Wikstrom and Treiber (2016) too found that drawing parallels between the situations with the immediate environment is problematic in the current literature. For instance, Wortley (2012) defined that a situation refers to a setting in which behavior occurs (p.186). Understood in this vein, most prior studies of situational theories attempt to address “how the immediate environment affects particular actions” (p.186). They explained that doing so conflates the two concepts – the situation should be the result of the person-environment interaction, contingent upon the motivation and perception that exists in that particular environment. Accordingly, Wikstrom (2006) defined an action as the outcome of the person-environment interaction, given the perception-choice process. On the routine-activity approach, Wikstrom and Treiber (2016) shared the same concerns articulated by

LaFree and Birbeck (1991) and argued that it is not a truly situational theory unless offender motivation and perception are considered. The consensus in these studies highlighted that the approach is merely predictive, rather than possessing the qualities of an explanatory model. The approach failed to account for the role of the environment that drives the motivation and causes the crime. The question of why some offenders choose to commit and not others remains unanswered. As such, the approach undermined its own aim of trying to explain the role of the environment, and it is obvious that individual perception and motivation do vary with changes to each confronting situation in the given environment.

2.2 Literature Review for R1 – Environmental Criminology

In this section, I frame the discussion of the notion of environmental structure referred to by LaFree and Birbeck (1991), Birbeck and LaFree (1993) and Wikstrom and Treiber (2016) using the framework of environmental criminology. To this end, Bruinsma and Johnson (2018) narrowed down the definition of an environment as "the constellations of factors that shape the spatial distribution of offenders and the crimes they commit" (p.1) and therefore environmental criminology consists of the study of the criminal opportunities for offenders and the spatial distribution of crimes, victimizations or offenders in society. They further explained that "the physical and social characteristics of these spaces are seen as having the potential to explain differences in the distribution of crime" (p.3).

Along the lines of the crime pattern theory proposed by Brantingham and Brantingham, (1993, 2008), my conceptualization begins with the observation that criminal opportunities are complex, not random and that the risk of victimization depends on the occurrence of specific situations in space and time (Miethe, Stafford, and Long, 1987). Brantingham and Brantingham (2013:537-539) explained nine factors that structure criminal opportunities and events. Most relevant to the current endeavor is the notion that criminal opportunities and events depend upon the environmental structure. In crime pattern theory, key aspects of environmental structure considered include nodes, paths and edges. The authors defined that "at the aggregate level, activity nodes are gathering places where large number of people congregate for specific purposes", such as the transit interchange or the central business district. Along similar lines, environmental criminologists Weisburd et al. (2009) and Braga, Papachristos and Hureau. (2010) posited that crime generators and crime attractors are activity nodes that have become crime hot spots for different reasons. Johnson (2014:194-195) further defined crime generators to be "…particular nodal areas whereby large number of people are attracted in the course of their daily routines and crime attractors to be particular areas which create well-known opportunities for particular types of crime to which intending offenders are attracted as a result of those known opportunities". Finally, paths between nodes are also the sites of many offenses. Property crimes are spatially clustered along paths between nodes, as research by Cohen and Cantor (1981) and Reynald (2009) suggested. For example, studies have found empirical evidence indicating that robberies, vehicle thefts, and thefts from vehicles are clustered along major roads and/or public transit stops (Beavon et al., 1994; Block and Davis, 1996).

According to Brantingham and Brantingham (1993:4)'s prediction, when a person lives in an area, more of the pathways become well-known as a result of daily routines in the area. Therefore, the coverage of the offenders' crimes is much wider when they are familiar with the area. A study conducted in 2016 tested their postulation by analyzing 447 offenses in close to 7,000 street segments from 2002 to 2007 in one London borough (Summers and Johnson, 2016). The authors hypothesized that street segments that are more accessible will be more familiar to everyone, including offenders. As a result, crime is positively related to the "centralness" of the street segment. Using a graph theory based methodology that measures the movement of people and vehicles across street segments, the estimates partly supported their hypothesis. While they found that the crime frequency is positively related to street segment to-movement and –through-movement for both people and vehicles analyzed independently, the results lost significance when analyzed jointly due to multicollinearity. Another limitation of the internal validity of the study is the failure to include major influences of the frequency of crime at both the micro and macro level. In spite of these weaknesses, the authors concluded that their results are largely consistent with prior research. The locations of serious crimes are systematically influenced by the spatial distribution of land use and configuration of the street networks, as predicted by the crime pattern theory.

2.2.1 Crime Concentration at Places

Using the definition of an environment provided by Bruinsma and Johnson (2018), in this section I review the evidence for crime concentration at places. Decades of criminological research have made clear that both a small number of victims and locations experience a huge proportion of all crime committed (Weisburd, Groff and Yang, 2012; Sampson, 2013) and there is no reasonable cause to assume that maritime piracy might be an exception. The findings shown in Figure 1 support this assertion.

One of the most influential papers on the nature of the spatially clustering of crime is Sherman, Gartin, and Buerger (1989). Using spatial data, the authors analyzed more than 100,000 calls to the police for service from addresses in Minneapolis. First, the results indicated that just 3 percent of addresses and intersections in Minneapolis produced 50 percent of all calls for service to the police for each year. Next, the authors analyzed the hot spots of predatory crimes. They found that all robbery calls were located at only 2.2 percent of all places, all auto thefts at 2.7 percent and all rape at just 1.2 percent of the places in the city. During the same year, 95 percent of the places in the city were crime free. However, Weisburd, Maher, and Sherman (1992) pointed out that the study did not examine the relationship among specific crimes at the addresses they examined. As a result, it might be possible that hot spots may just be the result of clustering of particular and specialized forms of criminality in discrete environments. They also argued that sources of error in call data and the less reliable nature of using dispatched calls as a measure for count of crime might render the results invalid. Drawing from the same data source but on a different time frame (1987 - 1988), the authors analyzed more than 5,000 addresses that included at least three "hard" crime calls. They discovered 365 hot spots (7.3 percent of all addresses) which account for more than a quarter of the total number of crime call events in the city. In a later study, Sherman (1995:36) defined "crime hot spots as small places in which the occurrence of crime is so frequent that it is highly predictable, at least over a one-year period". The author went on to assert that the concentration of crime at places is even greater than that among individuals, explaining that "future crime is six times more predictable by the address of the occurrence than by the identity of the offender" (p.36).

In Seattle, Weisburd et al. (2004) relied on official crime data on close to 30,000 street segments to examine the distribution of crime over a 14-year period covering 1.5 million incident reports. They found that between 4 – 5 percent of all street segments accounted for more than half of all incidents reports for each of the 14 years observed. In terms of the stability of crime concentration over time, they found that street segments with more than 50 reported incidents were concentrated in 1 percent of all street segments. Using trajectory analysis, they uncovered 18 trajectories, of which 7 were decreasing. These decreasing trajectories consisted of 14 percent of all Seattle street segments and were responsible for all of the city's crime decline.

Still based in Seattle, Weisburd, Morris, and Groff (2009) conducted a longitudinal study of the concentration of officially recorded juvenile crime using the street segment as the unit of analysis. Similar to the findings in Weisburd et al (2004), this study found that less than 1 percent of all street segments were responsible for half of crime; and between 3 – 5 percent of all street segments were responsible for all juvenile offending. The descriptive analysis suggested that "juvenile arrest incidents are highly concentrated in each year of the period being studied, and that this concentration of juvenile crime at place is fairly stable across the 14 years" (p.452) they examined. Relying on the trajectory analysis, the study identified 5 distinct groups. Three of the groups included less than 0.3 percent of all street segments but they were responsible for "about a third of all juvenile arrest incidents occurred on those street segments during the 14-year period studied" (p.454).

Curman et al. (2014) tested the external generalizability of the crime concentration thesis outside the US. In Vancouver, 7.8 percent of the street segments accounted for 60 percent of crime, and 60 percent of the street segments accounted for all of the city's crime. Wheeler et al. (2015) attempted an replication of the research design of Weisburd et al. (2004) and Curman et al. (2014) in the context of Albany, NY using part 1 and 2 crime data from 2000 to 2013. Analyzing more than 4,000 street units in Albany, the authors found that "…higher-crime micro places tend to remain higher-crime micro places in Albany" (p.585). As such, the authors drew the conclusion that "crime and place are tightly coupled together" and this statement is supported by findings which suggested that the "factors driving crime at micro places tend to be relatively stable over long periods of time" (p.606). Furthermore, criminologists who have examined beyond the street segments confirmed the spatial concentration of crime at larger aggregation spatial units at both the city and neighborhood levels. Mazeika and Kumar (2017) tested the external generalizability of crime concentration in two India cities. Analyzing burglary and motor vehicle theft, over 43 percent of vehicle thefts are "concentrated in approximately 2 percent of all the grid cells within the two cities, and all crimes within just over 11 percent" (p.54). As for burglary, the degree of clustering is greater than that of vehicle thefts, with "21 percent of offenses occurring in just 0.4 percent of grid cells, and all offenses occurring in just 4 percent" (p.56). There is a great deal of similarity between these two types of crime. Close to 96 percent of the grids experienced no crimes. Results based on the nearest neighbor hierarchical clustering identified five vehicle thefts hot spots accounted for 13 percent of crime and less than 0.1 percent of land area. A similar pattern exists for burglary.

2.2.2 Harm Concentration at Places

The environmental structure embedded within situational perspectives helps to inform our understanding of the concentration of crime at hot spots but it is silent on the concentration of the severity of crime across space and time. Given that situational perspectives emphasize the dynamic nature of the environment, the seriousness of crime need not remain constant across space and time. However, prior studies reviewed earlier treated all crimes as though they are created equally. In this subsection, I expand the premise of the definition of the environmental structure provided by Bruinsma and Johnson (2018) and discuss the concentration of *harm* spots across space and time, in addition to hot spots.

With few exceptions, past research in crime pattern theory and crime concentration at places treated all crimes as though they are the same. This approach is limited because all crimes are clearly not created equally, as the total cost of crimes estimates indicated. There is tremendous variation in the total cost of crimes across crime types in the most commonly cited studies as summarized in Roman (2009). For instance, according to estimates from the jury award literature, the total mean cost of crimes ranged from $4.18 million for murder to $19,370 for robbery and $551 for theft (in 2008 dollars) (Miller, Cohen and Wiersema, 1996). A more robust estimate by Roman (2009) using the propensity model puts the figures at $1.56 million for murder, $299,573 for robbery and $2,655 for theft (in 2008 dollars). In monetary terms, the price of one murder is equivalent to a range of 600 to more than 7,000 thefts. Regardless of the approach and statistics used to estimate the direct and indirect cost of crimes, the core message embedded in these studies is that all crimes are not created equal.

Sherman (2007, 2010, 2011, and 2013) and Sherman, Neyroud and Neyroud (2016) asked the question of what if the naïve assumption is relaxed so that crimes could instead be classified according to their harm, relative to other crimes. Studying the public perception of the seriousness of the crime has a long tradition in criminology, dating back to the works performed by Sellin and Wolfgang (1964) and Wolfgang et al. (1985) on crime severity. Knowing the harm associated with crimes is central to a wide range of policy analysis (Miller et al. 1993; Cohen et al. 2004; Cohen, 2005) as it could serve as the reference for the allocation of scarce criminal justice resources. However, none of these measures of crime seriousness have been used in the hotspots studies examined earlier, nor were they included by practioners as part of official crime reports. The landscape is changing rapidly in recent years, though, due to the continuing quest for a better accounting of harm caused to victims within the intellectual community. Sherman et al. (2016:173) evaluated four plausible approaches in which crime harm could be operationalized: 1) The assessment of harm framework proposed by Greenfield and Paoli (2013); 2) The court records approaches adopted in Canada and New Zealand (Francis et al. 2005; Sullivan and Su-Wuen, 2012); 3) Crime victim survey (Ignatans and Pease, 2016) and 4) The "sentencing gravity score" (Ratcliffe, 2015). The authors concluded that while some of these measure are too complicated to be operationalized by practioners (approaches 1 and 2), others are not stable enough to be comparable over time and place (approach 3). Taking these caveats into consideration, they built on approach 4 and operationalized the Cambridge Crime Harm Index (CHI) based on the "sentencing guidelines' 'starting point' recommendations of the number of days in prison for a first offender convicted of that offense" in the UK (Sherman et al. 2016:177). Sparrow (2008) noted that law enforcement is increasingly recognizing the merits of harm reduction, as oppose to merely order maintenance. The impetus for change is accelerated post-2009. Neyroud (2015) argued that as a result of criminal justice budget cuts after the 2008 Great Recession, police agencies are forced into innovative ways to prioritize limited resources and reassess their traditional focus of crime volume reduction. In spite of the renewed interest in the study of crime harm recently, the stability or variation of the temporal-spatial clustering of *harm spots* remain largely unknown to both scholars and practioners.

Most recently, a group of UK criminologists made significant contributions to the criminology of place literature by studying the patterns of hot spots and harm spots in the city of Birmingham. Using data on about 180,000 individual crime events, the authors calculated the harm values for each event by multiplying the number of CHI days in prison by the count of crimes. The street segment was used as the unit of analysis and the study found that around three percent of all street segments were responsible for all crimes, and slightly less than one percent of all street segments were responsible for all harm. Examining these 120,000 street segments, the authors identified hot spots, harm spots and what they called "co-locations" or overlapping areas of hot spots and harm spots. They argued that three categories carry tremendous public policy implications – 1) Priority crime areas (1.65 percent of streets segments were responsible for about 30 percent of crime and half of harm); 2) harm spots (1.21 percent of street segments were responsible for 4 percent of crime and 33 percent of harm); 3) Hot spots (2.33 percent of street segments were responsible for a quarter of crime and 5 percent of harm). This research is particularly noteworthy because it came up with an actionable plan for the police to guide their presence and activities based on the type of crime areas. It concluded that the most cost-effective way to deter crime is for the police to target their scarce resources to the Type 1 priority areas where hot spots and harm spots intersect.

Relatedly, a recent unpublished thesis supervised by Dr. Ratcliffe shed light upon the concentration of crime frequency vs harm debate on the offender-level (Liggins, 2017). The study tracked the “power few” offenders in Northamptonshire over time using the Cambridge CHI. Based on more than 300,000 offenses committed by around 40,000 unique offenders from 2010 to 2016, the descriptive statistics showed that “21.2 percent of offenders accounted for half of crime volume and 2.7 percent of unique offenders accounted for half of offender identified harm” (p.63). The longitudinal analysis also revealed that while the percentage of offenders contributing to 20 percent and 50 percent of harm remained relative stable over time at an average of 0.5 percent and 2.2 percent, respectively, the percentage of offenders contributing to 80 percent of harm fluctuated from a low of 5 percent to a high of 6.8 percent during the sampling period. Last, the average CHI for offenders who were responsible for 50 percent and 80 percent of harm remained fairly stable while that for 20 percent of harm exhibited wide variations, during the study period. The findings of this pioneering study contributed significantly to our limited understanding of the clustering of frequency and harm at the offender-level, finding a great deal of stability and variation of harm at varying levels of “power few” offenders.

In contrast to Liggins’s offender-level frequency and harm analysis, I study the spatial-temporal trends of grid-level hotspots and harm spots by calibrating the CHI of each pirate attack reported to the IMO, as will be described in great details in the next chapter. I compare and contrast Liggins's findings against the "power few" maritime piracy harm spots, which I define as the small percentage of grids that are responsible for a huge proportion of pirate attacks or harm. The "power few" offending for offender-level versus grid-level harm comparisons is unprecedented in the criminological literature. Its relevance for theory, policy and future research will be discussed in the concluding chapter.

In sum, sections 2.1 to 2.2 outlined the definitions of situational theories, evaluated the relative strengths and weaknesses of the current state of research.

2.3 Prior Studies Applying Environmental Criminology Perspectives to Maritime Piracy

Marchione and Johnson (2013)'s research was motivated by the principals of environmental criminology. They analyzed 34 years of piracy attacks and concluded that maritime piracy, like other forms of criminality, cluster in space and time. The authors used the Moran's I statistics to estimate the significance of the spatial clustering coefficient around hot spots of maritime piracy in Gulf of Aden, and the Malacca Strait among other places. They further employed the Mantel and Knox tests and concluded that "just like other types of crime, incidents of piracy cluster in space and time, and do so more than would be expected if their timing and location could be explained by the fact that some locations are more attractive to pirates than others" (p. 519). However, the article stopped short of elucidating the nexus between the space-time concentration of piracy and the core tenets of the routine-activity approach. In my view, exploring the space-time dynamics of pirate activities worldwide without accounting for the heterogeneity in underlying baseline hazards severely threatens the internal validity of their findings. Specifically, the motivation of pirates, mode of operation, target types and attractions, guardianship need not remain constant regardless of regional and location variations. A large body of research suggests that these situational characteristics possess nontrivial regional (see Liss (2011) for a comparison of the Asian- vs Somali- style of piracy), as well as location (see Lindsey (2015) which compare and contrast the routine activities of pirates at ports, territorial waters and international waters) heterogeneities that are relevant to account for any type of clustering. Combining all attacks worldwide together in a single regression specification washes out these important situational nuances. Also, the study failed to rule out alternative explanations for the space-time dynamics by not controlling for a set of relevant confounders in their modeling specifications. In this case, it might be subjected to the risk of omitted variable bias and inflating the degree of clustering.

Caplan, Moreto, and Kennedy (2011) acknowledged that the environmental conditions that enable pirate attacks to be carried out is an important but neglected area. They noted that prior research relied on descriptive analysis to support their narratives of the environment on the incidence of piracy, rather than performing systematic testing using statistical methods. To help fill this void, they argued that risk terrain modeling could be used to analyze the patterns of risk at micro units incorporating the known major risk factors. Three such factors were identified – shipping routes, state status and chokepoints, and a total of seven layers of risk maps were spatially joined to produce a risk terrain map. Using data from 2009, they estimated that pirate attacks clustered in 1.3 percent of all cells, with each cell measuring 42 by 42 nautical miles. The logistic regression analysis was chosen as a prediction tool, and the results showed that the 2008 risk terrain map correctly predicted 61 percent of pirate attacks in 2009, using the cell as the unit of analysis. The policy implication is that knowing ahead where piracy is most likely to occur helps to direct limited policing resources to the areas at risk during the appropriate times.

In my opinion, their RTM approach is limited on several fronts. First, the authors made an overstatement by claiming that the 61 percent prediction accuracy is “quite a feat” (p.110). Although what is considered a “good enough” prediction accuracy is often context dependent, in the case of piracy it is much more straightforward. There is relative stability in the spatial concentration in the patterns of attacks as demonstrated by Marchione and Johnson (2013). Analyzing 34 years of data, they found that piracy almost always occurs in the same locations, although the frequency of attacks fluctuates from year to year. Murphy (2010) and Liss (2011) reported that the basic style of piracy has been constant over time in Somalia and South East Asia, respectively. It is therefore not unreasonable to suggest that the prediction accuracy of the results is still quite a distance from being exemplary. Second, the study utilized the logistic regression as the classification tool. It turns out that numerous studies performed using Monte Carlo simulations which compared the prediction accuracy of logistic regression with respect to other classification tools such as the Bayesian classification and regression tree (CART) models, decision trees and random forests consistently proved logistic regression to be an inferior strategy (Berk and Bleich, 2013; Efron, 2007). Furthermore, given that classification is the central thrust of the paper and the techniques used underlie the set of policy recommendations, the authors failed to adopt measures most commonly used to validate logistic regression, such as the AUC (area under curve) of the ROC (receiver operating curve). Last, omitted variable bias is very likely to occur when only three explanatory variables were included for a large sample size of 88,093.

In terms of the impact of the physical environment on piracy, anecdotal evidence from the shipping industry suggest that there is a great deal of variation in terms of the average harm associated with each attack depending on the location of the attacks (Operations, 2011). Specifically, pirate attacks are most deadly in port areas, and least deadly when perpetuated in international waters. This makes sense because near port areas, ships are either stationary or travelling at lower speed due to the shallowness of the coastal water, which makes approaching and boarding tempting (Cook and Garrett, 2013). Also, at port areas the water is relatively calmer so pirate skiffs can approach targets at full speed without having to worry about the risk of capsizing. In comparison, ships generally travel between 12 – 14 knots in international water and the higher speed makes it challenging for pirates to approach and board. Also, when being chased, ships can adopt tactical maneuvers to avoid boarding. Last, the pirates are concerned about the amplitude of wave-height in international water as their skiffs could not withstand waves taller than 2.5 meters (Cook and Garrett, 2013). These location-dependent environmental factors matter a great deal in explaining the variations in the average harm per attack.

2.4 R1 – An Inductive Approach toward the Study of Environmental Criminology and Maritime Piracy

In contrast to a deductive approach of hypothesis testing, I decide to adopt an inductive approach by attempting to discover whether hot spots and harm spots do – or do not – concentrate at certain places across time. As my study protocol shown in the next chapter illustrates, my study design allows me to be open to all possible types of concentrations (optimized hot spot analysis, emerging hot spot analysis and local outlier analysis for both count and harm analyses). My intention for R1 is to explore any possible connection between the clustering of count and harm of pirate attacks over time worldwide as well as in multiple locations. The methods used for the inductive approach testing R1 will be explained in great details in the next section.

In conclusion, in section 2.3 I reviewed several prior studies that applied environmental criminology perspectives to study maritime piracy before presenting an inductive approach to examine the first research question R1 of my dissertation. Next, I perform a literature review for the second research of my dissertation.

2.5 Literature Review for R2 – Routine Activities Perspective

To examine the second research question R2, I first lay out the literature review for routine activities perspective in section 2.5. Next, I review key prior studies that relied on the routine activities perspective to study maritime piracy in section 2.6. Last, I adopt a deductive hypothesis testing approach and operationalize the four core tenets of the perspective (e.g. motivated pirates, absence of capable guardians, presence of suitable targets and convergence effect) to be tested in four hypotheses in section 2.7.

My second research question pertains to the quantification of the effects of offender motivation, target suitability and the absence of capable guardians and their convergence on piracy. In this section, I tap on the routine-activity approach to analyze these individual ingredients and their combined effect in a cohesive and unified manner.

Cohen and Felson (1979:591) discussed the features of the routine activities approach and noted that "… a criminal event involves not just that a person be willing to offend but also that he or she has the opportunity to act on these motives…". They further explained that "…each successful completed violation minimally requires an offender with both criminal inclinations and the ability to carry out those inclinations…" (p. 590). Last, the authors noted that for crimes that involve offender-target contact, there must be "a person or object providing a suitable target for the offender" and there must be an "absence of guardians capable of preventing violations" (p. 590). For these transgressions to take place, Felson (1998:4) stressed that "the three essential ingredients – 1) motivated offenders, 2) suitable targets, and 3) an absence of guardianship – must converge in time and space."

For the first component – motivated offenders – no measure of offender motivation is included in Cohen and Felson's (1979) original conceptualization of the perspective. It assumes that motivated offenders will be present in any settings, so it focuses more on variability in target attractiveness and guardianship. As a result, most existing research testing the empirical validity of the perspective takes motivation as given (Madero-Hernandez and Fisher, 2013). However, it is noteworthy to stress that the perspective does not assume that the degree of motivation in a population must be constant over time. To overcome this gap in the existing research, this study draws on decision theory and relaxes this assumption by estimating how variability across time influences crime.

The second element of the perspective is target attractiveness, which Meier and Miethe (1993) referred to as "the economic or symbolic value; an individual's inertia to attacks; and the ease of removal of a potential victim's property" (p. 472-473). Most of the existing literature operationalize the measurement of target attractiveness in terms of the economic value of the target. For example, some studies in theft victimization, robbery and personal larceny have relied on indicators such as whether cash is carried openly or handled, wearing of jewelry in public settings, possession of expensive goods and family income; while those related to burglary have used measures such as home ownership and real estate values (Sampson and Wooldredge, 1987; Miethe and McDowall 1993; Bernasco and Luykx, 2003; Messner et al., 2007; Zhang et al., 2007).

Third, Felson and Cohen (1980:392) defined guardianship as "…the supervision of persons or objects that can prevent crime from occurring…" The existing literature operationalize measures of physical guardianship using a variety of target hardening approaches (Wilcox et al., 1994; Fisher et al., 1998; Mustaine and Tewksbury, 1998; Outlaw et al., 2002). These include the installation of burglar alarm in homes, owning a dog and carrying a weapon by residents and their participation in self-protection trainings. One final noteworthy dimension of the theory pertains to the spatial and temporal interactions of the relationships among the three ingredients. As suggested by Felson and Cohen (1980:392) "…for transgressions to take place, the three essential ingredients – motivated offenders, suitable targets and an absence of guardianship – must converge in space and time…".

Notwithstanding a growing body of research supporting the perspective, studies testing its empirical validity face at least three methodological challenges – 1) cross-sectional design; 2) assumed motivation and 3) lack of convergence among the three ingredients. In a recent review of the perspective, Madero-Hernandez and Fisher (2013) argued that the bulk of existing empirical evidence on the validity of the perspective have primarily relied on cross-sectional designs. In the absence of longitudinal data, the authors argued that the predictive validity of the perspective will not be strong. Next, prior tests of the perspective that have involved measurement at a given point in time assumed that offender motivation is constant. While such an assumption may hold true in a cross-sectional design, I note that motivation need not remain constant longitudinally, as predicted by the rational choice theory and acknowledged by LaFree and Birbeck (1993) and Wikstrom and Treiber (2016). Researchers have consistently demonstrated that there is considerable variability of economic motivation across time (Bushway and Reuter, 2002; Van der Geest et al., 2011; Uggen and Wakefield, 2008). This study specifically addresses these limitations by using a longitudinal data set that allows me to measure different levels of motivation in a population over time by drawing on decision theory, given that the routine-activity approach essentially assumes a motivated offender and focusses on the lack of guardianship and target attractiveness.

2.6 Routine Activities and Maritime Piracy

The routine-activity approach emphasized that predatory pirate attack requires the combination of a motivated pirate (or a group of motivated pirates at the aggregate-level), a suitable ship, and the absence of a capable guardian, which will be outlined next. Variation in the occurrence of this combination, generated by differences in daily routines, will cause piracy rates to differ. If the circumstances in South China Sea grants more opportunities for pirates to consider unguarded ships, piracy will increase. Parallel to the argument made by Felson and Clarke (1998) “opportunity makes the thief”, it is not unreasonable to postulate that opportunity makes the pirate. Furthermore, changes in the benefits related contagion effects, whether the attack was reported will affect the number of pirate attacks. The routine-activity approach can be regarded as a special case of the rational choice perspective. The situation determines the benefits and cost of various courses of action, and piracy is assumed to be increased by the benefits and reduced by the costs.

Piracy being a situated event is inextricably coupled to the environment. Pirate attacks are events - they are not random but are known to cluster in space and time. Pirates choose their targets. Pirate attacks have temporal or seasonal patterns. The presence of the pirate is only one of the necessary ingredients: Piracy requires many conditions that are independent of the pirate, such as the availability of ships to be hijacked or of valuable cargos to be stolen. Although environmental criminologists have claimed that piracy is a situated event (Townsley, 2018), the direct empirical testing of the routine-activity approach remains scarce, with few exceptions. Among those that did, the explicit testing of the theory in its entirety which consists of the three components and their convergence, was never performed to the best of my knowledge. Thus, environmental criminologists have no evidence to conclude whether piracy is indeed a truly situated event. Here, I assess the strengths and weaknesses of both qualitative and quantitative attempts that partially tested the routine-activity approach and piracy. Next, I derive four hypotheses based on the three components of the approach and their convergence.

Shortland and Vothknecht (2011) adopted a qualitative approach to examine the guardianship component of the routine-activity approach. Through a series of interviews with government officials and shipping industry players, they concluded that the effect of the arrest and trial of pirates is weak in the Gulf of Aden. It is challenging to prove in court that the suspected perpetrator is indeed a true pirate, given that the crews of suspicious skiffs are very likely to jettison their equipment before arrest. Moreover, the interviews revealed that ship owners are not always willing to have their crews testify because they do not want to be labeled as unreliable carriers and they dislike the effort and time involved in prosecuting pirates in courts where the criminal justice procedures are notoriously inefficient. The authors concluded that “in the context of violent and lawless Somalia, these sanctions may be perceived to be toothless” (p.137), and “the naval forces in the Gulf of Aden (adopting the catch and release policy) has not achieved its declared aim of eliminating piracy in the region” (p.150).

Shane and Lieberman (2009) collected IMB data from 2003 through 2009 and applied the routine-activity approach partially to explain the frequency of attacks. The authors offered a set of situational recommendations for reducing piracy (e.g., fortified engine rooms, requiring containers to be registered), but do not provide empirical tests to support these recommendations. As a result, we have no evidence about whether the set of situational strategies is effective. Most recently, Lindley (2015) applied the routine-activity approach to explain the onset, persistence and desistence of piracy in Somalia. Through a descriptive analysis, the author argued that the onset could be attributed to the offenders’ motivation in terms of grievances (toxic waste dumping and illegal, unreported and unregulated (IUU) fishing,) as well as greed (increasing ransom payments). She noted that access to suitable targets in the Gulf of Aden and off the Horn of Africa help explain the persistence of piracy. Vessels suited to piracy victimization include small and slow moving vessels and merchant ships. Other ingredients of suitable targets include the volume of international trade transiting the Gulf of Aden, flag state policy, as well as the weather and seasonal patterns. With regards to the aspect of guardianship, she reviewed the effectiveness of several counter-piracy responses from international organizations, governments, nongovernment organizations and private companies from a qualitative perspective. Although this is the most systematic and comprehensive attempt at applying the routine-activity approach to the study of piracy, no formal statistical procedures were performed to validate the hypotheses. Without strong evidence, it is hard to draw solid conclusions regarding the validity of the approach applied to piracy.

Apart from Marchione and Johnson's recent empirical analysis, the criminological literature on the routine-activity approach and maritime piracy have generally been descriptive. Given that the empirical determinants of maritime piracy from a routine-activity approach remain largely unknown, the time is ripe for a study of the effects of offender motivations, suitable targets, and absence of guardianship on the incidence of maritime pirate attacks. To fill the near void of the routine-activity approach to study piracy, I next develop a set of theoretically-informed expectations about the impact of factors that structure piracy as well as the presence of guardianship on vessels on the risk of being attacked. To the best of my knowledge, this is one of the first empirical applications of the routine-activity approach for piracy.

2.7 R2 – Applying the Routine Activities Perspective to Maritime Piracy

At the beginning of this section, it is noteworthy to highlight that in the context of piracy, I am applying the perspective to a more macro environment because I cannot measure the micro elements directly (e.g. individual ship-level data on whether each ship is pirated or not and specific guardians, etc.). The macro factors can probabilistically affect the three components of the perspective, but they do not absolutely predict them. Granted, I have no data on 1) ships that were not pirated; 2) the suitability of all ships (pirated and unpirated); 3) guardianship for all ships (pirated and unpirated). Thus, the perspective cannot be tested directly.

Instead, I am using the routine activity-approach as a theoretical guide to motivate hypotheses. For instance, just because military spending is high does not mean that specific ships will have guardianship. Since these data are not available, I am using proxies that presumably vary in similar ways to the actual elements. Thus, I change from absolute to probabilistic terms and by doing so, a regression approach that include noise is justified. The methods will be explained in great details in the next chapter.

2.7.1 What Motivates Offenders of Maritime Piracy Based on Decision Theory

In his study on maritime piracy in South East Asia, Vagg (1995) concluded that piracy is an attractive and ‘thinkable’ complement to fishing in many Indonesian villages located on remote islands. Hampered by pervasive poverty and lack of legitimate employment opportunities, many disadvantaged fishermen were attracted by merchant ships passing at low speed and close to shore--ships that can feed an entire village (Dinakar and Maurer, 1999). While a small number of risk-loving fishermen became full-time pirates, many became what Frecon (2006) referred to as “stand-by pirates” – those who were part-time fishermen and part-time pirates. The fisherman-pirate income substitution model is also confirmed in another research which will be discussed later (Ludwig and Fluckiger, 2015). Piracy would seem to be the logical choice as they possess the necessary equipment, such as ropes, long knives and boats; possess the maritime navigational skills and familiarity with the geographical area; and have first-hand knowledge of the movement patterns of the merchant ships passing by based on daily observations. In his interviews with villagers and chiefs in the pirate-infested Riau Archipelago area, Frecon (2006) summarized that they are sympathetic and condone piracy as an acceptable means in search of better economic prosperity. On a similar note, Stuart (2001) observed that while pirate attacks are usually conducted by a small number of able-bodied men on behalf of the community for food, cigarettes and cash, the entire village may support and admire the perpetrators. Thus, it is reasonable to predict that the incidence of piracy attacks will increase when the economic conditions of littoral countries in the Malacca Strait and the South China Sea are deteriorating.

Next, it has long been established that there exists a relation between crime and season and crime seasonality is a source of predictable variation (Durkheim, 1951; Carbone-Lopez and Lauristen, 2013; McDowall et al., 2012). One of such pioneering studies that examined the temporal clustering of crimes is Quetelet (1842), which discovered that rates of property crimes were higher during winter, whereas crimes against persons were higher during summer. Contemporary research rely on much more sophisticated methodologies. For instance, using process control chart techniques, Anderson and Diaz (1996) found that the seven FBI crime categories have more activity during the Christmas holiday season in Houston, Texas between 1983 and 1993. Similarly, Sisti et al. (2012) relied on official statistics on deaths by homicide from 2003 to 2008 in Italy to study variation in peaks across the year. Using spectral analysis and circular statistical techniques, the authors found that homicide peaks during the Christmas holiday season (December and January) and summer holiday season (July and August). Last, both McPheters and Stronge (1974) and Jud (1975) reported that rates for property crime (particularly against tourists) increased during the holiday seasons in Miami and Mexico City, respectively. Similarly, studies in policing have found “hot times and days” (Sherman, 1992). Sherman (2013) reported that “crime risks vary enormously by time of day and day of week, as well as season by season and holiday by holiday" (p. 24). These and other studies (Carbone-Lopez and Lauristen, 2013; McDowall et al., 2012) concluded that there is variation across time in level of economic need. At traditional times when there is a high demand for material goods (e.g., Christmas and school holidays) instrumental crime rises.

I acknowledge that the routine-activity approach is a victimization theory that focusses on two of the three components and simply assumes a motivated offender. In the following Hypothesis, my modeling of the variation around a motivated offender draws on rational choice. Along this line of reasoning, I hypothesize that the risk of piracy attacks is higher during holiday seasons when economic needs are high.

Hypothesis 1: The hazard of piracy will increase in times of economic need.

2.7.2 Are There Capable Guardians Against Maritime Piracy?

After an extensive literature review, I identified three major forms of guardianship that could potentially impact the risk of piracy. The first is military spending by the littoral countries in the Malacca Strait and South China Sea. It is reasonable to assume that the coast guard and navies of the littoral countries are by and large the primary guardians against pirates in the region. However, as Djalal (2004) reported, the scale of operation was severely hampered by the onset of the 1997 Asian Financial Crisis and the 2008 Great Depression. Many obsolete vessels were unable to be modernized and those in operation were poorly maintained. In the aftermath of the 1997 Asian Financial Crisis, Umbach (1998) estimated that the military spending of Southeast Asian countries were reduced by a third, with the exception of Singapore. For the case of Indonesia, only 25 out of 115 navy vessels were operational at any given time. Djalal (2004) further noted that the country needed a minimum of 300 navy vessels in order to maintain law and order on its maritime territory. The Indonesian Navy's lack of resources is conducive for piracy to thrive in its maritime jurisdiction – perpetrators are emboldened to carry out attacks with little fear of being apprehended. The routine activity perspective posits that all else being equal, pirate attacks are likely to become more common place when the presence of capable guardians shrinks.

Next, the littoral countries in the Malacca Strait reacted to the spike in maritime piracy by adopting several strategies aimed at regaining control in the affected region. Two major events stand out as representing increased guardianship. One of the most elaborate and extensive efforts to combat piracy in the Malacca Strait is the military intervention named "MALSINDO" (an abbreviation based on the names of the three countries involved – MALaysia (MAL), SINgapore (SIN) and InDOnesia (DO)). Officially beginning in July of 2004, MALSINDO established a joint-command system between the three countries so that navy vessels from one country can conduct hot-pursuit of pirate ships into the territory of another country. According to Schuman (2009), each country is required to commit 5-7 navy vessels to jointly patrol major shipping lanes situated in the Malacca Strait and the South China Sea. The author reported that the effort is subsequently reinforced in July 2005 by joint aerial surveillance through the "Eye in the Sky Initiative" which involved the regular aerial reconnaissance conducted along major shipping lanes in the region. The aerial data is then sent to the joint-command center through a web-based information sharing network so as to enhance strategic planning of coordinated patrols. It is reasonable to hypothesize that the risk of piracy is higher prior to the implementation of MALSINDO, compared to after.

The second military intervention is "Cooperation Afloat Readiness and Training" (CARAT). Started in 1995, it consists of a series of annual bilateral military exercises conducted by the respective navies of the Philippines, Indonesia, Malaysia, Thailand, Brunei and Singapore with the United States Seventh Fleet. Each year from May to August, more than 1,000 US marines, sailors and coast guardsmen hold joint military exercises with the land, sea and air forces of the host countries. The joint-training events include live-firing exercises, amphibious raids and counter piracy and maritime terrorism search and rescue operations. For instance, during the 1999 CARAT Singapore phase, more than 2,000 officers and men from the US Navy and Republic of Singapore Navy, 17 ships from the special warfare units and diving units, as well as aircrafts from both countries participated in the exercise. I include this event because the sudden increase in the joint military operations in the region could post a significant threat to pirate activity. Conversely, I argue that during the rest of the year when CARAT is not in operation, the risk of pirate attacks is likely to be high, as the routine activity perspective predicts.

Hypothesis 2: The hazard of piracy will increase during periods of time when MALSINDO and CARAT are absent.

2.7.3 What Creates a Suitable Target?

Merchant ships transiting the South China Sea are clearly attractive targets because of their high value and the economic value of the goods carried onboard. For emerging economies like China and the industrialized states of Japan and Korea ever so dependent on crude oil imports from the Middle East, approximately a third of the world's crude oil supply carried by more than 20,000 oil tankers ply the region every year. Given that production and demand are seasonal, Liu et al. (1997) showed that the export and import series of Asian countries have a regular seasonal pattern. As both the volume and value of trade increase, the sheer frequency with which situations present themselves make piracy both attractive and easy in these ‘crime attractors’ and ‘generators’. Finding suitable targets of high economic value is not difficult for motivated fishermen who are based in islands within the Riau Archipelago as they are situated along one of the world’s busiest waterways - the Philip Channel. Daily observations provider them the opportunity to develop ‘cognitive maps’ of their environment and consequently, they are very likely to be aware of the variation in value of trade across time. Offenders play an active role in deciding which targets they see as attractive and capable of being victimized when their routines and daily experiences engender a comprehensive conceptualization and mental framework that predefine the rudiments of a suitable target, as discussed in great detail in Brantingham and Brantingham (1993) and Wilcox et al. (2003). Along this line of reasoning, I develop hypothesis three:

Hypothesis 3: The hazard of piracy will increase when the value of trade passing through the region is high.

2.7.4 Convergence Effect

A pirate attack involves not just a pirate willing to offend but also locating suitable vessels in the absence of capable guardians to capitalize on these motives. The compounding effect of motivated offenders, absence of capable guardians and suitable targets provides the final hypothesis which predicts that the risk of piracy attacks is positively related to the intersection of the three ingredients. It should be noted that in the pure sense of the routine-activity approach, there will be no pirate event without all three elements in place.

Hypothesis 4: The hazard of piracy will increase when measures of absence of capable guardian intersects with both the measures of motivated pirates and suitable targets.

Summing up, in sections 2.5 and 2.6 I first reviewed the routine activities perspective before discussing past studies that attempted to study piracy through the lens of the perspective. In section 2.7, I derived four hypotheses related to the three ingredients and their convergence based on the routine-activity approach. They are operationalized in the next chapter and the results are presented in chapter 4.

2.8 R3 – Literature Review for Rational-Choice Theory

My third research question R3 seeks to measure the specific effect of economic conditions of Somali fishermen on piracy. I argue that the rational-choice perspective is the most appropriate theoretical model to conceptualize this research question. The conceptualization for R3 proceeds as follows. In section 2.8, I first review the literature for rational-choice theory before launching into the discussion of economic condition and maritime piracy in Somalia in 2.9. In 2.10, I evaluate the quality of the empirical studies testing the link between economic conditions and crime. Finally, I lay out an economic model based upon the rational-choice perspective, and explain the derivation of the hypothesis related to the theoretical prediction of the perspective.

Adam Smith who adopted an individualistic approach to human behavior noted the importance of circumstances in explaining crime. He stated that: "…nothing tends so much to corrupt mankind as dependency, while independency will increase the honesty of the people. The establishment of commerce and manufacturers, which brings this independency, is the best police for preventing crime. The common people have better wages in this way than in any other, and in consequences of this a general probity of manners takes place through the whole country. Nobody will be so mad as to expose himself upon the highway, when he can make better bread in an honest and industrious manner" (Smith, 1763:155-156). Applying this line of reasoning to the current context, variations in the environmental conditions affecting the economic outcomes of fishing activities may have a rather direct detrimental effect on piracy. Differences in piracy between fishermen over time may be explained as the result of the rational behavior for given preferences under various circumstances. During periods of low fish capture production, unemployment of fishermen reduces the feasible set of actions, and allocating more of their time to pirating may become the best alternative strategy according to given preferences, as predicted by the economics of crime models of Becker (1968) and Ehrlich (1973). Therefore, in this section I invoke the rational-choice perspective to conceptualize the second research question.

The focus on the proximate situation and opportunity leads to the exploration of how offenders make the decision to break the law. One popular suggestion – rational-choice perspective – is that offenders are rational in the decision they make. The intellectual roots of rational choice theory can be traced directly to the work on utilitarianism by Jeremy Bentham (1789:1), who defined utility as "the weighted balance between two opposing considerations—pleasure (benefits) and pain (costs)", that is the guide to human conducts. In his work "*The Principles of Morals and Legislation*", Bentham argued that "human behavior is directed by the twin goals of the attainment of pleasure and the avoidance of pain" (p.1). The principle of utility pleasure and pain drives pain and pleasure — utility is a function of actions that bring pleasure and disutility is a function of pain. A rational individual is assumed to maximize the sum total of his actions such that they generate a net positive utility.

Interests in the theory revived in the 1960s after decades of neglect and criticisms by criminologists of the era. The seminal article by Becker (1968) was based on an interpretation of crime that was similar to thoughts posited by philosophers such as Bentham (1789) and Beccaria (1764). Using the expected utility model, Becker showed that the decision to offend is influenced by the benefits and costs of crime and legitimate activity. Examples of these costs include the formal legal punishments, and loss in earnings. He noted that the certainty of punishments is more important than severity. To make punishment effective, the credibility of the threat of sanctions requires the expected sentence to be positive. The desistance from crime of a rationally calculated individual is therefore a function of the severity of punishment (Patternoster, 1989). To prevent crime among the population at large, therefore, criminal law must emphasize penalties to incentivize citizens to obey the law. Under the assumption that criminals engage in rational decision making upon choosing among a range of legal and illegal activities, Becker argued that crime prevention efforts should focus on making crime an irrational option. This entails increasing the costs and reducing the benefits of illegal activities.

Relying on the utilitarian frameworks introduced in Ehrlich (1967) and Becker (1968), Ehrlich (1973) presented an economic model of the optimal time allocation between legal and illegal market activities. Assuming there is no cost to move between the two and entry costs are not required, an individual is faced with two activities – legal activities with certain rewards and illegal activities with risky rewards in accordance with Becker's (1968) formulation. When the marginal expected return to illegal market activities exceed legal market activities, the author showed using Kuhn-Tucker nonlinear programing mathematics that a risk-neutral offender who seeks to maximize the expected utility would dedicate more time in illegal activity compared to a risk avoider. For a risk-loving offender, the author showed that he will dedicate more time to illegal activities compared to both the risk-neutral and risk-averse offenders.

Recent criminological literature tested the empirical validity of the rational-choice perspective in a variety of contexts using advanced statistical techniques. LaFree et al. (2009) empirically examined the impact of the deterrence and backlash models for terrorist violence in Northern Ireland. Relying on duration analysis, the paper found some support for both the deterrence and backlash model. Specifically, the three government interventions, namely internment, criminalization and the Gibralter Incident increased the hazard of subsequent attacks. The magnitudes of the backlash effects were computed to be 87, 55 and 59.8 percent respectively for these three interventions. The government intervention Operation Motorman was associated with a 46 percent decrease in the likelihood of subsequent attacks, indicating the presence of deterrence effects.

LaFree et al. (2012) studied the temporal and spatial patterns of attack by the group ETA between 1970 and 2007 from a rational choice perspective. After the group announced in 1978 that it would shift its strategy of attack, the paper tested whether decision making on the part of ETA is strategic or not. The authors argued that prior to 1978, control attacks were predominantly the mode of choice whereas after 1978, the group shifted towards attrition attacks that diffused hierarchically. They found that diffusion was more likely to occur in these provinces during the attrition period. Specifically, 43.7 and 64.0 percent of the diffusion of attacks were hierarchical for the control and attrition periods respectively. Further analysis through multinomial logistic modeling indicated similar results and moreover, as the duration between attacks increases, subsequent attacks were more probable to be against non-contagious provinces.

In a study of terrorist behavior in Israel by Dugan and Chenoweth (2012), the authors used rational choice approaches to examine to what extent punishing and rewarding actions affect the frequency of terrorist attacks. Their results showed that "repressive actions were either unrelated to terror or related to subsequent increases in terror, and conciliatory actions were generally related to decreases in terror, depending on the tactical period" (p.597).

Last, Carson (2014) tapped on the rational choice framework to examine radical eco-groups and counterterrorism. Series hazard modeling was used to analyze the Eco-Incidence Database (EID) which drew data through the Global Terrorism Database (GTD) from 1970 to 2011. Results from the series hazard model indicated that the AETA intervention was associated with a decrease in hazard of another attack, animal-only attack and damage-only attack by 47, 52 and 42 percent respectively. After the implementation of the ADA intervention, there was 11 percent drop in the hazard of another attack and 15 percent decrease in an environmental-only attack.

In this section, I framed the testing of economic conditions and crime through the rational-choice perspective structured in a series of economics of crime studies like Becker (1968) and Ehrlich (1973). I also reviewed the criminological studies that explored this relationship. The key notions of the perspective discussed here are operationalized in the next chapter.

2.9 The Case of Economic Conditions and Maritime Piracy in Somalia

The tight coupling between economic conditions and piracy is not a new phenomenon. As early as 1924, Ormerod (1924:69) documented that "fishermen in the Ancient Mediterranean regarded piracy as a means of production". They resorted to piracy when fish productions were low, leveraging on their navigational knowledge, seafaring skills and equipment. Surprisingly little has changed in the modern times. In the recent literature on maritime piracy, a substantial body of studies (Frecon, 2005; Murphy, 2009; Liss, 2011; Daxecker and Prins, 2013) still observed that pirates often have a background in fishing which gives them a natural advantage in getting acquainted with the local patterns of maritime traffic. It is reasonable to speculate that economic shocks affecting the fishing industry will likely influence the frequency and prevalence of pirate attacks. Elleman et al. (2010:43) aptly labeled fishermen who engage in piracy to make ends meet as "occasional pirates". To them, "piracy was typically a seasonal job… and that fishermen turned to supplement their incomes from lawful activities" (p.43). In Southeast Asia, Frecon conducted interviews with Indonesian pirates and it showed that pirate syndicates tap on unemployed fishermen and sailors for recruitment. Similar to Elleman, Frecon labeled these fishermen as 'part-time pirates' or 'standby pirates' (Frecon, 2006).

One study estimated that there were between 700 to 800 IUU fishing boats in Somali waters during 2005, capitalizing on the state's failure to police and control its own Exclusive Economic Zones and fishing territories (Agnew et al. 2009). It suggested that the great majority of the total annual fish catch can be linked to IUU. According to a United Nations Food and Agriculture Organization (FAO) report[xii], the IUU fishing vessels extract “an estimated $300 million worth of seafood” from the one of the world’s richest fish ground's coastline annually, especially lucrative catches such as lobsters, sharks, tunas, rays, anchovies and shrimps. They consisted of two sources – regional vessels from neighboring littoral countries, and international vessels from Europe and Asia. Waldo (2009) observed that more often than not, these IUU vessels neither compensate the local fishermen nor pay taxes. Some IUU vessel operators would even procure unofficial fishing licenses issued by warlords and corrupt officials.

The FAO report added that many IUU fishing vessels exploit underwater explosives that kill all species indiscriminately (including endangered species such as sharks, whales and sea-turtles) in order to maximize their catch. Moreover, illegal equipment like nets with very small mesh sizes were utilized and to lure fish to their traps and sophisticated underwater lighting systems were illegally deployed. Artisanal Somali fishermen were outclassed, whose industry had always remained small-scale, and they could not afford the advanced technologies of their interloping competitors[xiii]. Consequently, the foreign IUU fishing vessels stole an indispensable source of protein and wherewithal from some of the world’s poorest people and ruined the subsistence of a great number of legitimate Somali artisanal fishers[xiv].

In response, Somali fishermen reported to the UN special envoy for Somalia of being threatened and attacked by foreign fishermen with guns and repelled with water cannons, their nets confiscated, boats destroyed, and other abuses suffered in the course of making a legitimate living on their own national fishing territories[xv]. Unfortunately, their pleas to the international community for assistance to eradicate the country's shores of IUU vessels went unanswered (Menkhaus, 2009). Consequently, some of these impoverished fishermen were forced to take arms to defend their own fishing territories so as to ensure that the supply of fish which their livelihood depended on is sustainable. Villages around ports such as Harardhere, Kismayo and Eyl became the dens of 'pirate gangs' such as the "Somali Marines" and "National Volunteer Coastguard of Somalia" who vowed to protect themselves against foreign IUU vessels. They claimed to play a pseudo state-like security role in ensuring that the sovereignty of their country and the lives of Somalians are protected against foreign invasions (Diaz and Dubner, 2010; Sone, 2010). As a result, piracy is a reasonable response to economic impoverishment due to overfishing. According to the legitimacy "Robin Hood narrative" posited by Schneider and Winkler (2013:185) of Somali pirates, kidnapping is culturally condoned and is seen by the locals as a form of special "taxation" to make up for the loss caused by foreign invasions. Their narrative was supported by interviews conducted by Schbley and Rosenau (2013) with UN officials and Somali government leaders.

Beyond IUU fishing, Somali fishermen have long accused foreign ships of dumping radioactive waste material and toxic industrial and hospital waste off the country's shores, polluting the coast and poisoning the marine ecosystem (Menkhaus, 2009; Sone, 2010). After the 2004 tsunami hit the country, solid evidence regarding the illegal dumping of toxic wastes emerged (Charlebois, 2012). A United Nations Environment Program (UNEP) spokesperson stated that: "…the tsunami washed rusting containers of toxic waste onto the shores of Puntland, northern Somalia". He added that: "…(they) exposed a terrifying activity that had been going on for over two decades. Regarding the content of those containers, he stated that "(the waste) consists of many different kinds, ranging from uranium radioactive waste, heavy metals such as lead, cadmium and mercury, industrial waste, chemical wastes to hospital waste"[xvi]. In 2005, the United Nations Development Programme conducted an on-site investigation along the Somali coast, reaching the conclusion that "…the dumping of toxic and harmful waste is rampant in the sea, on the shores and in the hinterland" (UNDP, 2005:1). Ghosh (2014) explained that illegal toxic dumping is a hugely lucrative business. For instance, proper toxic waste disposal in Europe costs roughly $1000 per ton whereas it costs only $2.50 per ton along the Somali coast.

The *Ecologists* reported that since the hazardous materials were exposed, hundreds living in the coastal village have "…fallen sick, suffering from skin infections, mouth and abdominal bleeding, as well as a whole range of chronic and acute illnesses related to cancer" (Milton, 2009:1). Similarly, a *Time Magazine* article cited "uranium radioactive and other hazardous deposits leading to a rash of respiratory ailments and skin diseases breaking out in villages along the Somali coast" (Tharoor, 2009:1). The article went on to assert that "…many local doctors said that they had treated more cases of cancer in one year than they had in their entire professional career before the tsunami". Other than poisoning Somali fishermen, the danger of the radioactive uranium waste contaminating the ocean and causing the coastal ecosystems to collapse cannot be underestimated. In response, impoverished fishermen/pirates who claimed to be members of the "National Volunteer Coastguard of Somalia" took speedboats to intercept and seek compensation "fees" on the foreign vessels. These narratives were supported by a report on the links between piracy and IUU fishing by a nonprofit research and analysis organization which shed light on the emergence and development of piracy through a qualitative approach (Schbley and Rosenau, 2013).

2.10 Prior Studies Testing Economic Conditions and Maritime Piracy

Although the tight coupling of economic conditions and piracy has long been established through qualitative studies, rigorous statistical testing of this common wisdom is relatively new. Here, I attempt to summarize and critically evaluate this strand of research.

Recently, there is an emerging body of research that highlights the association between economic conditions and maritime piracy (Jablonski and Oliver, 2012; Daxecker and Prins, 2012; Ludwig and Fluckiger, 2015). Overall, they found that different measures of economic conditions are negatively related to the frequency of pirate attacks. This relationship remains valid when the specific measure of economic conditions is the fish output production. Their findings thereby substantiated the 'occasional pirate' and 'stand-by pirate' propositions of prior qualitative studies. The major caveat of these three recent studies is the risk of reversed causality, which occurs when the increased probability of being pirated may deter or discourage fishermen from going fishing. I next discuss them in detail.

First, Jablonski and Oliver (2012) analyzed to what extent the frequency of pirate attacks is influenced by the fluctuation in commodity prices. The authors concluded that the frequency of pirate attacks can be explained by the variation in the prices of agricultural products. They reasoned that the reduced prices of commodity prices lowered the opportunity costs in engaging in piracy. Second, Daxecker and Prins (2013) showed that the annual frequency of pirate attacks were inversely related to the growth rate of the fish production. Unfortunately, the study failed to address the potential endogeneity between fish capture production and the frequency of pirate attacks. Qualitative analysis conducted by Bueger, Stockbruegger and Werthes (2011) also argued that the main contributing factor to piracy is negative shocks in the fisheries sector as a result of IUU fishing. However, the authors did not offer systematic tests of their narratives.

In my assessment, however, the available evidence related to economic conditions and piracy could have been stronger. First, Daxecker and Prins (2013) could have addressed the endogeneity of economic variables to piracy in greater details and their causal relationship is open to interpretations. The issue arises when pirate activities are a function of the number of fishing boats. This function is positive when pirate activities are linked to the increasing presence of fishing boats since it is “easier to hide among a greater number of vessels”, as the research by Kraska (2011:37) suggests. On the other side of the coin, the function is negative when pirates are absent and that fishermen increase their effort. When the function is positive, the coefficient will be most likely biased upwards, and vice-versa when the function is negative. In Appendix 1, I show mathematically the nature of the endogeneity problem inherent in their method.

<Insert Appendix 1>

In the application of the linear model on fish production and incidence of piracy in Daxecker and Prins (2013), it is possible that some regressors are endogenous, e.g., fish production correlated with the error term. In this situation, OLS cannot consistently estimate the causal effect of fish production on the incidence of piracy. These concerns suggest that more could be done in this area to overcome the lack of exogeneity.

Bearing these limitations in mind, Flückiger and Ludwig (2015) attempted to resolve the lack of exogeneity issue through instrumenting. Using 0.5 by 0.5 degree grids as the unit of analysis in a panel study, they concluded that “negative economic shocks in the fisheries sector are associated with an increase in maritime piracy” (p.118), which corroborated with prior studies. They used an innovate approach and instrumented economic shocks with phytoplankton abundance within the Exclusive Economic Zone (EEZ) (which is defined as 200 nautical miles off the individual countries' coasts). Their first stage analysis indicated that “plankton abundance is positively related to fish capture production, but negatively associated with the incidence of piracy” (p.116). The specific magnitude of the effect is such that “a plankton shock that induces fish capture production to decrease by 10 percent increases the risk of piracy occurring by 10 percentage points” (p.116).

In my view, the major *strength* of the paper– the choice of phytoplankton abundance as an instrument for fish production and hence the economic well-being of the fishermen – is truly an innovative strategy to overcome the lack of exogeniety. However, it remains debatable whether phytoplankton abundance and economic conditions of the country, or the fishermen/pirates are truly exogeneous. Two conditions must be met in order for an instrumental variable to be valid: 1) the covariance between the instrument and the independent variables must be non-zero (“relevance”); and 2) the covariance between the instrument and the error term is zero (“exogeneity”). Evidently, phytoplankton abundance is adversely affected by coastal environmental degradations such as dumping of toxic waste, which in turn occurs as a result of poor economic conditions and lack of governance in a failed state like Somalia as explained earlier. As a result, the exogenous variables (phytoplankton abundance) which are correlated with the endogenous regressor (fish production) is correlated with the error term. Therefore, it remains unclear whether Flückiger and Ludwig (2015) can accurately estimate the causal effect of fish production on the incidence of piracy.

Summing up, recent empirical studies are getting increasingly sophisticated in their methods to tease apart the complex processes through which economic conditions can affect piracy. Building upon this body of established literature, in the next chapter I introduce a novel instrumental variable regression approach in an attempt to confront these challenges.

2.11 R3 – Rational-Choice Predictions of Maritime Piracy

In accordance with the economics of crime models under the rational-choice perspective, this section explains how Hypothesis 5 is derived. As outlined earlier, the rational-choice perspective can be traced directly to economics of crime framework of Becker (1968), Ehrlich (1973), Heineke (1978) and Cook (1986). It should be noted that in contrast to Ehrlich (1973), the original Becker (1968) model did not explicitly consider crime as a problem of time allocation. To formulate Hypothesis 5, I build on Ehrlich (1973)'s "Optimal Participation in Illegitimate Market Activities" framework to model the behavior of fishermen/pirates who are assumed to allocate their time between legal (fishing) and illegal (pirating) activities.

In his theoretical model of optimal time allocation between legitimate and illegitimate activities, Ehrlich assumed that leisure time is fixed so that the remaining time is strictly split between legitimate and illegitimate activities. In other words, a pirate maximizes his expected utility based on the optimal devotion of his time to either fishing or pirating. In Appendix 2, I prove that the equilibrium proportion of time devoted to fishing is a negative function of the legitimate income from fishing activities. This means that the fisherman/pirate devotes more time to piracy when fish capture production is low. In Hypothesis 5, I rely on data from East Africa and Malacca Strait and South China Sea to test the strength of the relationship between economic conditions and crime in these two regions. Specifically, it is stated as:

Hypothesis 5: *The hazard of piracy is inversely related to the fish capture production in East Africa and Malacca Strait and South China Sea*

<Insert Appendix 2>

Summarizing, past qualitative research and anecdotal evidence from various UN organs suggest that the emergence of pirate gangs in East Africa is the reasonable response to IUU fishing and coastal pollutions. Impoverished and unemployed Somali fishermen resort to piracy as a culturally-tolerated means to supplement subsistence fishing. Given the evidence indicating that the ‘part-time/standby pirates’ in Southeast Asia are very much operating in the same ‘Robin-Hood’ spirit as their East African counterparts (Frecon, 2006; Murphy, 2009), Hypothesis 5 is tested using data from both East Africa and Southeast Asia.

For the third research question R3, I drew upon the rational-choice perspective to understand the phenomena of economic conditions and piracy in East Africa. While there are a few studies that quantitatively measured this effect, I argued that they suffer from inadequate choice of instruments, misspecification and overall inappropriate modeling strategies. Therefore, the effect of economic condition on piracy cannot be estimated in an exogenous or clean manner. I presented an economic crime model to make rational sense of the time allocation between fishing and pirating in section 2.11.

2.12 Chapter Summary

This chapter invoked three core perspectives embedded within situational theories of crime to help conceptualize the three main research questions I will explore. After defining and reviewing key notions and studies in situational theories, I reviewed the core elements within environmental criminology, the routine activities perspective and the rational-choice theory. Next, I conceptualized these theories within the context of piracy. Findings from key studies that tested them on piracy are summarized and the quality of evidence is evaluated. Finally, five hypotheses are derived based on the theoretical predictions of this basket of situational theories. As argued in the opening statements, the application of mainstream criminological theories to conceptualize the study of maritime piracy is not impossible, and they are beginning and will continue to exert significant influence in the conceptualization of piracy. The next chapter introduces the data, presents the main methods used for the analyses and operationalizes the key theoretical constructs.

Chapter 3: Data and Methods

In this Chapter, I outline the data used in the study, operationalize the measures adopted and provide a detailed description of the analytic strategies used for the three research questions. It proceeds as follows. I start off with an introduction with the sources of the data and their sample sizes in section 3.1. For the methods used to test the first research question R1, the optimized hot spot analysis of frequency, inverse distance weighting, space time cube, emerging hot spot analysis and local outlier analysis, are laid out in 3.2 to 3.5.

Moving on to the second research question R2, I operationalize the measures adopted which include the dependent variable, independent variables (offender motivation, absence of capable guardian, suitable target, context, and convergence) in 3.6 to 3.16. To test R2, I exploit a variety of methods based on different underlying assumptions. They are the series hazard model, testing the proportional hazard assumption, alternative survival function, as well as Bayesian analysis. No single one of these methods may provide conclusive evidence because they are based on different assumptions but when they are all put together, an acceptable conclusion can be drawn if the findings are the same. Although the Bayesian methods are in my view appropriate robustness checks, I decide not to include them as part of the main text because they do not provide a set of different conclusions compared to the series hazard model, which is the main workhorse for my analysis. Their equations and results are instead presented in Appendix 3.

For the third research question, the measures adopted (dependent variable, instrumental variable, independent variable, controls) are operationalized in 3.17 to 3.20. R3 is tested using the structural equation models for hazard function in 3.21, when the identifying assumptions in 3.22 are satisfied. For similar reasons argued in R2, an IV Cox proportional hazards model (3.23) is used as a robustness check in Appendix 3. 3.24 concludes the section.

3.1 Data

In this section I explain the salient characteristics of the database used for the ensuing modeling approaches. My dissertation relies on pirate attacks worldwide that were drawn from the Piracy and Armed Robbery Reports in the Global Integrated Shipping Information System (GISIS) developed by the International Maritime Organization (IMO) which compiled the first monthly incident report in 1982.[xvii] According to the IMO, the data are voluntarily submitted by ship owners, masters, as well as international organizations and member states. Information provided in the data set includes the date of the attack, ship name, ship type, location of the attack, region of the attack, geographical coordinates (from 2006 onwards), incidence details, consequences for crews, the authorities to which the incident was reported and coastal state actions. I link available variables to each of the major theoretical perspectives that guide the research. This database is the most widely used in previous scholarly research (Percy and Shortland, 2009, 2013; Shortland and Vothknecht, 2011; Psarros et al. 2011; Townsley and Oliveria, 2013; Bryant et al. 2014; Shane and Magnusin, 2014), as well as various international organizations (Dugato and Berlusconi, 2015; Bowden et al. 2010). The nature of the data is just like 911 calls and self-reported victimization data. For the former, violent crimes are more likely to be reported while petty crimes tend to be underreported due to the hassle of cooperating with the local police and possible demurrage charges. For the latter, under reporting is likely because the carriers do not want to be stigmatized as an unreliable carrier and risk the possibility of an increase in insurance premium. The repercussions of these limitations will be discussed in the final chapter. These limitations notwithstanding, I argue that call data is considered to be the most reliable and complete source of crime data for studying geographic patterns, providing a less filtered picture than what arrest reports may provide. The spatial and temporal extent of the data for each research question will be noted in the subsequent sections.

Another notable database for pirate incidents that is less commonly used in prior research is the NGIA Anti-Shipping Activity Messages (ASAM) (Marchione and Johnson, 2013; Townsley et al., 2015). Compared to the IMO database which draws close resemblance to self-report victimization data, the ASAM database is more of an amalgam of police recorded crime and self-report data because it includes incidents reported by multiple agencies such as the IMO, coast guards, navies and even news agency reports around the world. Given that the definition of maritime piracy adopted is not standardized across these reporting agencies, in the ASAM database many 'non-piracy' incidents according to IMO standard are included, such as cases related to civil conflicts and other crimes in the ocean. The ASAM database also suffers from duplicate entries as the same incident could be submitted multiple time by different reporting agencies. As a result of these limitations, I rely on the IMO-GISIS database for my dissertation.

3.1.1 The Cambridge Crime Harm Index

To compute the total harm associated with each pirate attack, I rely on two sources – the Aviation and Maritime Security Act of 1990 and the Cambridge Crime Harm Index (CHI) as described in Sherman et al. (2016). According to Part 2 of the

Aviation and Maritime Security Act 1990 – Offenses Against The Safety of Ships and Fixed Platforms - Article 9, the offense “Hijacking of ships” is defined as: “A person who unlawfully, by the use of force or by threats of any kind, seizes a ship or exercises control of it, commits the offence of hijacking a ship, whatever his nationality and whether the ship is in the United Kingdom or elsewhere, but subject to subsection”. Article 9 states that: “A person guilty of the offence of hijacking a ship is liable on conviction on indictment to imprisonment for life”. Under Article 11, the offense “Destroying ships or fixed platforms or endangering their safety” is defined as: “…a person commits an offence if he unlawfully and intentionally— 1) destroys a ship or a fixed platform, 2) damages a ship, its cargo or a fixed platform so as to endanger, or to be likely to endanger, the safe navigation of the ship, or as the case may be, the safety of the platform, or 3) commits on board a ship or on a fixed platform an act of violence which is likely to endanger the safe navigation of the ship, or as the case may be, the safety of the platform”. Similar to Article 9, the punishment of this offense is stated as: “A person guilty of the offence of hijacking a ship is liable on conviction on indictment to imprisonment for life”. According to Schedule 21 (Determination of Minimum Term In Relation to Mandatory Life Sentence) of the Criminal Justice Act 2003, I interpreted “imprisonment for life” to mean 20 years (Taylor, Leng and Wasik, 2004) and coded the number of CHI prison days for these two offences to be 365*20=7,300 CHI prison days.

Given that the definitions, interpretations and sentence lengths of crimes vary across countries (Newman, 1999; UNODC, 2010), I rely upon the Cambridge CHI to provide a common currency that quantifies the true cost of all piracy-related crimes across space and time. Following the methodology used by Sherman et al. (2016) to compute the crime harm scores for each offence using sentencing guidelines in England and Wales (Sentencing Council, 2017), I select the following offenses from the CHI which are most relevant to maritime piracy: 1) Murder - victim one year of age or older (5,475 CHI prison days); 2) Firearms - Have a firearm with intent to commit an indictable offence (2,555 CHI prison days); 3) Kidnap - common law (548 CHI prison days); 4) Possess knife blade or sharply pointed article (18.75 CHI prison days); 5) Robbery professionally planned commercial (730 CHI prison days); 6) Burglary other than dwelling - With intent to steal (10 CHI prison days); 7) Public Order - S4 Harassment - put in fear of violence (42 CHI prison days).

The crime harm score for each attack is coded as the sum of all offences committed according to the Incident Summary Report of the IMO-GISIS database, excluding the harm inflicted to the perpetuators. I use the following example taken from the IMO-GISIS database to illustrate the coding process:

"Around 14 robbers armed with AK47s and knives boarded and hijacked the anchored tanker. They damaged the tanker's communication equipment and sailed it to an unknown location where a part of the cargo was transferred to another ship. Prior to leaving the vessel on 09.10.2012, the pirates stole the crew's personal belongings and cash." (IMO No. 9358917)

In this event, the following offences are committed: 1) Hijacking of ships (CHI=7,300); 2) Destroying ships or fixed platforms or endangering their safety (CHI=7,300); 3) Firearms - Have a firearm with intent to commit an indictable offence (CHI=1,825); 4) Kidnap - common law (CHI=548); 5) Possess knife blade or sharply pointed article (CHI=18.75); 6) Robbery professionally planned commercial (CHI=730). I therefore coded the harm of this attack to be 7,300+7,300+1,825+548+18.75+730=17,721.75 CHI prison days.

R1) To what extent does environmental criminology, crime pattern theory and crime concentration at places improve our understanding of maritime piracy?

In the first research question, I assess whether a small proportion of location experience a large proportion of all crimes committed and harm. To do so, I rely on the optimized hot spot analysis, inverse distance weighting, space time cube, emergent hot spot analysis and local outlier analysis. The concentration of both count and harm are analyzed in these approaches.

My analysis of R1 is based on 2,563 pirate attacks worldwide, 1,083 pirate attacks in East Africa and 817 pirate attacks in Malacca Strait and South China Sea combined, from 2006 to 2014. Both spatial and temporal information for each attack are utilized for the analyses. The year 2006 is chosen as the starting point because it is the first year whereby pirate attack geo-coordinates are systematically recorded in the IMO-GISIS database. This study period is appropriate because it captures the peak and trough of maritime piracy worldwide, as well as in each of two regions. The IMO-GISIS database contains all relevant information for testing R1 and no ancillary data are necessary. The geographical data analysis and modeling from 3.2 to 3.8 are performed in R Studio 1.0.153 (with additional packages *raster, sp and lubridate*) and ArcMap 10.5 on a six cores server with 16 GB of RAM. The software ArcScene 10.5 that I relied on to create the volcanoes for the crime count and total harm clustering for each grid in 3.2 is commonly used in architectural analyses for creating blueprints. For 3D visualization of the concentration of crime count and harm around the globe, the software ArcGlobe 10.5 is used.

3.2 Optimized Hot Spot Analysis of Frequency

In the optimized hot spot analysis, I rely on the Getis-Ord local statistics which is a x-score to calculate whether attacks with different values show any signs of spatial clustering (Ord and Getis, 1995). Using my data, the term is defined as:

$$G_i^* = \frac{\sum_{j=1}^{2563} w_{i,j}x_j - \bar{X}\sum_{j=1}^{2563} w_{i,j}}{\sigma\sqrt{\frac{n\sum_{j=1}^{2563} w_{i,j}^2 - \left(\sum_{j=1}^{2563} w_{i,j}\right)^2}{n-1}}} \tag{1}$$

Where the matrix $W = (w_{ij:i,j=1\ldots241})$ is a spatial weight matrix summarizing the spatial relations between the coordinates of the 2563 attacks. Specifically, each spatial weight, w_{ij}, reflects the spatial influence of attack j on attack i.

Taking into account spatial dependency and multiple testing, a hot spot is calculated as a statistically significant location where attacks have high z-scores and be surrounded by attacks with similar characteristics (Schloeder et al., 2001). Through the spatial process defined in G_i^*, a map showing statistically significant hot spots is generated. On the contrary, a map of statistically significant cold spot is generated by finding the clustering of attacks that have low z-scores and be surrounded by attacks with similar characteristics.

3.3 Inverse Distance Weighting (IDW)

For any unmeasured locations within the study area, I rely on the technique of Inverse Distance Weighting (IDW) to predict hot or cold spots using some linear combinations of the known attack (Lu and Wong, 2008). The predicted value is defined as:

$$Z(x) = \frac{\sum_{j=1}^{2563} d_j^{-u} z_j}{\sum_{j=1}^{2563} d_j^{-u}} \tag{2}$$

Where the term d_j^{-u} is measured as the distance between the prediction attack and attack j; u is the factor that affect the drop in weight as distance increases.

Xie et al. (2011) interpolated soil pollution with four methods (IDW, kriging, radical basis functions, and local polynomial). They assessed the accuracy of the results through cross-validation and asserted that the IDW technique attained a high prediction accuracy. Therefore, I adopt the IDW technique to predict the values of interpolated attacks. The approach is particularly useful to shipping companies because the algorithm interpolates areas of hot spots in unmeasured locations and predict where ships should avoid.

3.4 Space Time Cube

Miller (2004) discussed Tobler's First Law of Geography and spatial analysis in great detail and noted that near or distant things are not the only important piece of information, "but rather that near is a meaningful starting point for geographical investigation" (p. 288). Building on this argument, I draw upon Hägerstrand's (1970) conceptualization of time geography as two geographical dimensions - space and time dimensions - with a spherical relation. As described in Chapter 2, there is a great deal of evidence of spatial-temporal clustering in maritime piracy attacks. It is therefore essential to extend the optimized hot spot analysis and develop a three-dimensional mapping of piracy attacks. The geo-visualization of the space time cube is discussed at great length by Nakaya and Yano (2010) as well as others (Kraak, 2008; Tompson and Townsley, 2010). To provide visual evidence of changes in attack concentration and trends, I rely on the simultaneous geo-visualization of two-dimensional optimized hot or cold spots and duration of attacks in a space time cube to perform two analysis – emerging hot spot analysis and local outlier analysis. However, after a thorough search, I was unable to locate any study that utilized the local outlier analysis, and found only one that studied forest loss using the emerging hot spot analysis. Harris et al. (2017) employed the emerging hot spot analysis using ArcGIS to identify space time trends of forest loss in four countries over a span of 14 years. In the data preprocessing stage, they created a series of space time bins of 2.5 km by 2.5 km by 1 year that covered the entire study region and aggregated forest loss points into each of these bins. Using the ArcGIS emerging hot spot analysis tool, the authors identified a series of new hot spots, intensifying hot spots, persistent hot spot and diminishing hot spots for each country.

Before presenting the map symbolization of the results in the next chapter, I describe the key data preprocessing steps required to construct the space time bin. First, the piracy data which include the date of the attack, longitude, latitude and cumulative harm for each attack is loaded into R. Using the *lubridate* package in R, the dates are standardized and converted to a format recognizable by ArcGIS. Next, the *raster* package is called upon to set the coordinate reference system to WGS1984. The data is then exported as a ESRI shapefile. Before transforming the data in ArcMap 10.5 to Network Common Data Form, I rely on the map projection tool to project the coordinates of the attacks onto a flat surface. To construct the space time cube, a set of coordinates is aggregated into a 'bin' that measures x miles by x miles by one time step interval as shown in Step A of Table 1. In Step B, The value of each bin is assigned as the frequency of attacks in that bin in a given year, and the trend of frequency over time is evaluated. I created three space time bins – one at the global scale using one set of parameters across all regions, one at the Malacca Strait and South China Sea region, and one at the East Africa region.

<Insert Table 1>

<u>*3.5 Emerging Hot Spot Analysis and Local Outlier Analysis*</u>

After constructing the space time cube, the space time clustering of attacks is estimated using the Getis-Ord local statistics introduced earlier to identify the optimized hot spots, as well as the non-parametric Mann-Kendall (MK) trend statistics to assess the temporal trends over the course of the study period. Computed using the G_i^*, the Z score for each space time bin which measures the degree of clustering within the bin relative to its neighboring bins in the space time cube. Due to the space time nature of the cube, neighboring bins consist of both space and time neighbors. Spatial neighborhood is defined using the "Queens Case" contiguity method (Cliff, 1968), whereby all adjacent bins that share an immediate border as well as those touching only at the corner. Temporal neighborhood is defined to be one time-step interval (one year) immediate prior to the bin itself. In turn, the sum of the Z score of all bins is compared to that of one particular bin, as well as its neighbors. If the sum of Z score for a particular bin is too large ($Z>1.96$) or too small ($Z<1.96$) to have occurred by random chance compared to its neighbors, as well as all bins, then there is statistically significant evidence ($p<0.05$) to indicate that there is hot spot or cold spot of piracy attacks compared to other bins, as well as all of the bins in the space time cube.

The MK trend statistic is used to determine if a statistically significant trend could be detected from the 2006 to 2014 time-series of Z-scores of each individual bin. For two sets of observations X and Y, the MK statistic is defined by:

$$S = \sum_{i<j} a_{ij} b_{ij} \tag{3}$$

Where $a_{ij} = sgn(x_j - x_i) = \begin{cases} 1, x_i < x_j \\ 0, x_i = x_j \\ -1, x_i > x_j \end{cases}$ and $b_{ij} = sgn(y_j - y_i) = \begin{cases} 1, y_i < y_j \\ 0, y_i = y_j \\ -1, y_i > y_j \end{cases}$

Assuming the law of large numbers hold and normality is satisfied, and the set of observations in Y is replaced by the time order of the series X, the MK statistic can be interpreted as a trend test and defined as:

$$S = \sum_{i<j} a_{ij} = \sum_{i<j} sgn(x_j - x_i) \tag{4}$$

The standardize test statistics for S and its one-tailed test p-value can be expressed as:

$$Z = \begin{cases} \frac{S-1}{\sqrt{\sigma_S^2}}, S > 0 \\ 0, S = 0 \\ \frac{S+1}{\sqrt{\sigma_S^2}}, S < 0 \end{cases} \tag{5}$$

$$p = 0.5 - \frac{1}{\sqrt{2\pi}} \int_0^{|z|} e^{-\frac{t^2}{2}} dt \tag{6}$$

In words, an increasing trend means that the Z-score for the first-time step is smaller than that of the second time step. No trend is detected when the Z-score for the first-time step is equals to that of the second time step. A decreasing trend means that the Z-score for the first-time step is larger than that of the second time step. The expected sum for Z is zero by definition. The actual sum is then compared to the expected sum to assess whether there is statistically significant evidence for the difference between the two. The trend is statistically significant when the p-value is less than or equals to 0.05.

The combination of G_i^* and S are used to categorize each bin time series into one of 17 categories. They comprise of eight types of hot spots, eight types of cold spots and one category for non-significant finding. This classification scheme for the emerging hot spot analysis and local outlier analysis is explained in Step C and D of Table 1, respectively.

Summing up, in the first question I tap on a basket of geospatial analytical techniques and spatial modeling approaches to examine whether a small proportion of location experience a large proportion of all crimes committed and harm. I introduce the data and modeling approaches taken for R2 next.

R2) How do offender motivation, target suitability and the absence of capable guardians and their convergence impact the instantaneous risk of piracy in South East Asia?

The data for the second research question R2 is first introduced before I outline the analytical approaches. As explained in the introduction, the robustness checks are not included in the main text because they essentially provide the same conclusion compared to the main estimation strategy, the series hazard model. Before presenting this model, I first operationalize the key measures for motivated offenders, absence of capable guardians, suitable targets and the convergence of these three terms. The proportional hazards assumption is tested to ensure that the findings possess a high degree of internal validity.

The ensuing survival analyses are based on 438 and 1,676 pirate attacks in Malacca Strait and South China Sea, respectively, from 1995 to 2010 using the IMO-GISIS database. Only the temporal information for each recorded attack is used in the analyses. Ancillary data on the GDP, import (carried, insured and freight or cif) and export (free on board or fob) values, unemployment rate, inflation rate are obtained from Census and Economic Information Center (CEIC) Data Manager.[xviii] As noted in the introduction, I rely on the series hazard model as the main estimation strategy. The accelerated failure time model and Bayesian analysis are used as robustness checks and they are presented in the Appendix.

3.6 Dependent Variable

The dependent variable for the test of routine activity theory is "Days Until Next Attack", which measures the time (in days) to each event from the time of the previous event[xix]. The clock is set to zero after each attack. In the South China Sea, the first attack occurred on January 1, 1995 and this date was set to be the time origin as it marks the onset of continuous exposure to risk of piracy attack in the data set[xx].

3.7 Independent Variable – Offender Motivations

I include two variables to operationalize the 'time of economic need' theoretical construct stated in Hypothesis 1. First, I include the variable "Regional Misery Index" which is computed as the sum of the yearly inflation and unemployment rates in each of the littoral countries along the South China Sea. Because the unemployment rate is inversely related to the inflation rate according to the Phillips (1958) curve, including these two terms individually will lead to multicollinearity. Here, I follow Tang and Lean (2008) and use the Misery Index to control for both of these effects on the risk of piracy without the multicollinearity concern. The Regional Misery Index is taken at the time of each attack. Table 2 shows that the mean of the series for the South China Sea is 8.890, with a minimum and maximum value of 4.159 and 14.143.

<Insert Table 2>

The second variable that captures the 'time of economic need' theoretical construct is "During Ramadan". "Lebaran" is the period of celebration at the end of Ramadan - the ninth month of the Muslim calendar. It is the most festive holiday in Muslim-majority countries in the region, such as Indonesia and Malaysia whereby it is a tradition for workers to gather with their family members. Although one might anticipate lower rates of crime during a holy holiday such as Ramadan, research summarized in Section 3.4 shows that in fact crime increases during holiday seasons in Western countries. Pirates are highly motivated because they are incentivized to bring home extra wherewithal for the celebration. The stronger the drive of the pirates, the more risk they will be willing to take on and hence the likelihood of piracy increases. It is therefore reasonable to hypothesize that the hazard of ships being attacked is likely going to increase during the month of Ramadan. Ramadan is a yearly recurring event[xxi] and piracy attacks perpetuated during these periods were coded as "1" and "0" otherwise. As can be seen in Table 2, the mean is 0.110.

<u>*3.8 Independent Variable – Absence of Capable Guardians*</u>

I include the variable "Regional Military Expenditure" to assess the hazards of piracy due to the absence of coastal enforcement in the area. The yearly military expenditure for countries located along the South China Sea are added and then divided by the sum of the value of GDP in these countries to derive the vector of regional military expenditure as a percentage of GDP to provide a common currency of comparison across the countries. It is taken at the time of each attack. I assume that the higher the regional military expenditure as a percentage of GDP, the higher is the guardianship (for ease of interpretation, the direction of the variable is reversed). In Table 2, the mean of the series is -1.832.

Next, I use a series of dummy variables with values of "1" if the piracy attack does not occur during any of the MALSINDO or CARAT events, and "0" otherwise. Since MALSINDO officially began in July 2004 but was not fully implemented until the "Eyes in the Sky" Initiative was launched in July 2005, I take the midpoint of these two dates and code attacks recorded from January 2005 until the end of the sampling period as "0" and "1" otherwise. In the South China Sea, CARAT starts on either May or June each year.[xxii] The duration of CARAT for each country is usually around two months. 69.5 percent and 82.6 percent of the piracy attacks are perpetuated when MALSINDO and CARAT are not in operation.

3.9 Independent Variable – Suitable Targets

To assess the impact of the attractiveness of targets by region, I include the variable "Regional Trade", which represents the cumulative value of trade passing through the region on a quarterly basis for the years 1995 to 2010. Cumulative trade is measured as the sum of export values (fob) from the following group of countries - Malaysia, Brunei, Vietnam, Thailand, Philippines, Taiwan, Macau, Hong Kong, China, South Korea and Japan - to the European Union, plus import values (cif) from the European Union to the 11 Asian countries/territories included in the analysis. For example, since the value of cumulative trade in the South China Sea for the second quarter of 2000 was 85,817.99 million USD, I code the variable "Regional Trade" with a value of "0.858" for each of the 35 piracy attacks recorded from April to June 2000. As shown in Table 2, the mean of the series is 1.201.

3.10 Context

The first variable under Context is "Success Density". A large success density indicates a high success probability for most of the recent incidents. Holden (1986) found evidence of a contagion effect when successful hijacking generated attempts of the same type. Also, Dugan et al. (2005) found that success density was positively associated with the hazard rates of aerial hijacking. From a methodological standpoint, it is crucial to control for the possible confounding contagion effect. For the case of piracy, when pirates witness the success of previous attacks, the incentive to engage in the next attack may manifest externally. To account for this possibility, I adopt the approach employed by Dugan et al. (2005) - using the temporal ordering of piracy attacks to construct a success density measure by taking the current and two previous attacks, and calculating the probability of success divided by the duration of the current event from the second previous event, weighted by 365 days. Mathematically, it is defined as $\frac{P(success\ for\ current\ and\ two\ previous\ attempts)}{(event\ date_{current} - event\ date_{second\ previous})/365}$. The mean of the series is 69.227 as Table 2 shows.

The second variable under Context is "Last Reported". When the piracy attack is reported to the coastal state, enforcement vessels or helicopters may be dispatched to the scene for rescue and investigation. To account for the possibility that the presence of enforcement agencies may deter nearby pirates, I include a measure of whether the last attack was reported to the coastal authorities. The mean of the series is 0.751.

3.11 Convergence

The convergence of the three elements of the routine activities perspective is created by taking the convergence of Motivation*Absence of capable guardians*Suitable targets. To construct the convergence term, it was necessary for all the component variables to be in the same metric. Because some of the variables were dummy variables (During Ramadan, MALSINDO, CARAT, Merchant Ships), this meant that the continuous variables (Regional Misery Index, Regional Military Expenditure and Regional Trade) had to be dichotomized. In the next section, I am going to define how I operationalize this term very specifically. The caveat associated with this process is discussed in the final chapter.

Because the series hazard model I use is fairly elaborate, I first explain how it can be applied to study the hazards of piracy attacks before presenting the results.

3.12 Series hazard Model

Following Dugan (2011), I use the series hazard model, which is an extension of the Cox (1972) proportional hazard model, to estimate the impact of the temporal variation in measures of criminal motivation, suitability of targets, and guardianship on the hazard of an additional piracy attacks controlling for a set of relevant variables. The following specification for the hazard model is used in the analysis:

$$h(Y) = \lambda_0(Y) \exp(\beta_1 \mathit{Criminal\ Motivations} + \beta_2 \mathit{Suitable\ Targets} + \beta_3 \mathit{Absence\ of\ Capable\ Guardianship} + \beta_4 \mathit{Context}) \quad (7)$$

where β is a vector of parameters to be estimated, and $\lambda_0(Y)$ is the unspecified baseline hazard function. The baseline hazard function corresponds to the probability of a pirate attack when all the covariates have values of "0." In this study, I assume the unspecified baseline hazards for Malacca Strait and South China Sea are the same since they are contiguous and share many unobserved characteristics. Ties are handled by an approximation method proposed by Efron (1977)[xxiii], and the standard errors are adjusted for the clusters[xxiv] in the Malacca Strait and the South China Sea.

I make the following three assumptions in the models. First, a significant increase in the hazard of new piracy attacks during Ramadan and periods of increase in the Misery Index are consistent with the motivations effect. Second, a significant increase in the hazard of new piracy attacks when the value of trade is high is consistent with the suitability of targets effect. Third, a significant increase in the hazard of new piracy attacks when major government counter-piracy interventions are not in operation is consistent with the absence of guardianship effect.

3.13 Convergence Term

I use the following specification for the hazard model to assess the impact of the convergence of criminal motivation, target suitability and absence of capable guardians, on the hazard of ships being attacked in the Malacca Strait and the South China Sea.

$$h(Y) = \lambda_0(Y) \exp (\beta_1 \textit{Criminal Motivations} + \beta_2 \textit{Suitable Targets} + \beta_3 \textit{Absence of Capable Guardianship} + \beta_4 \textit{Context} + \beta_5 \textit{Three-way Convergence Term}) \quad (8)$$

where β is a vector of parameters to be estimated, and $\lambda_0(Y)$ is the unspecified baseline hazard function.

As explained in Chapters 2, the convergence term refers to the convergence in time and space of the three core components of the routine-activity approach. To construct this term, I dichotomize the continuous variables "Regional Military Expenditure" by splitting the variable at its median and assigned the value of 1 to the *i*th observation when its value is below the median of the series. I further dichotomize the two continuous variables "Regional Misery Index" and "Regional Trade" by splitting the variables at their medians and assigning a value of "1" to the *i*th observation when its value is equal or above the median of the series. Additionally, only one of the measures for each of the three core components needs to take on a value of "1" to be considered in effect. For example, "Absence of Capable Guardian" is considered to be in effect when either the absence of MALSINDO, the absence of CARAT or low Regional Military Expenditure is present. After dichotomizing the covariates at their medians, the convergence term is constructed as the product of "Regional Misery Index", "Absence of Capable Guardian" and "Regional Trade". This term takes the value "1" only if "Regional Misery Index", "Absence of Capable Guardian" and "Regional Trade" take the value of "1". In the subsequent analysis, I assume that if the hazard ratio is greater than 1 and statistically significant, the convergence in time and space of the three central tenants of the routine activities perspective is associated with a high hazard of ships being attacked. The limitation of this dichotomization process will be noted in the final chapter.

3.14 Testing the Proportional Hazard Assumptions

With the Cox model used in the above analysis, the overall goodness-of-fit of the model is evaluated using a graphical diagnostic tool by creating a residual plot from the fitted regression model. When the proportional hazard (PH) assumption does not hold, it may be detected from the residual plot. There are many suggested residuals in the literature (see Collet, 1994 for an in-depth discussion). To check the PH assumption in empirical studies, Hosmer and Lemeshow (1999) argued that the scaled Schoenfeld residual (Schoenfeld, 1982) proved to be one of the most useful. The Schoenfeld residual for the *i*th covariate of the *j*th subject whose observed survival time is t_j is given by:

$$\hat{s}_{ij} = x_{ij} - \frac{\sum_{l \in R(t_j)} x_{il} \exp(x_l^T \hat{\beta})}{\sum_{l \in R(t_j)} \exp(x_l^T \hat{\beta})} \tag{9}$$

Denote the covariance matrix of $\hat{s}_j = (\hat{s}_{1j}, \dots, \hat{s}_{pj})$ by $\sum$ and its estimator by $\widehat{\sum}$. Then each component of the transformed residual $\hat{s}_j^* = \widehat{\sum}^{-1} \hat{s}_j$ is called the scaled Schoenfeld residual.

When the scaled Schoenfeld residual $\hat{s}_j^*$ is obtained from the PH model with estimated coefficient $\hat{\beta}_i$ while in fact the true coefficient should be $\beta_i^*(t)$ depending on t, it can be shown that:

$$E(\hat{s}_{ij}^* + \hat{\beta}_i) \approx \beta_i^*(t) \tag{10}$$

Thus, $\hat{s}_{ij}^*$ is plotted against t_j, the observed survival time for all subjects whose survival times are completely known. Under the PH assumption, the residuals should scatter smoothly around the horizontal line at 0 for the *i*th covariate. In the evaluation, any noticeable pattern or trend would indicate a time-varying effect for the covariate and weakens my findings. Therefore, I argue that it is necessary to assess the $\hat{s}_j^*$ to maximize confidence in the results.

3.15 Robustness Checks

The Cox semi-parametric proportional hazard model used in the preceding section has the obvious advantage that hazard ratios are estimated without making any specific assumptions about the underlying survival functions. An alternative to this commonly used model is the accelerated failure time model, which Wei (1992) defined as "a parametric model that assumes that the effect of a covariate is to accelerate or decelerate the life course of a ‘disease’ by some constant” (p. 1872). Wei found that the semi-parametric models are less efficient than their parametric counterparts when the right distributional assumptions were made. In model adequacy assessment using numerical studies, the parametric survival model is preferred over its semi-parametric counterpart, assuming that it can be fitted to the data robustly (Chen, 2001).

To select the parametric survival models that best fits the data, I next focus on two criteria - the Akaike’s Information Criteria (AIC) (Akaike, 1974) as well as the Schwartz’s Bayesian Information Criterion (BIC) (Schwarz, 1978). Haughton (1988) and Poskitt (1987) summarized that these criteria were designed to take into consideration different “penalties” to avoid overfitting. The optimal model is one with the smallest criterion value for either the AIC or BIC. They are defined as:

$$AIC = 2k - 2ln(\hat{L})$$

$$BIC = \ln(n)\,k - 2ln(\hat{L})$$

Where $\hat{L}$ denotes the maximized likelihood function and k is the number of unknown parameters.

<Insert Table 3>

The test results are reported in Table 3. As seen, the ‘non-monotonic’ survival models (log-logistic, log-normal) consistently outperform the ‘monotonic’ survival models. In both Malacca Strait and South China Sea, the log-normal model outperforms the exponential, Weibull, and log-logistic models. Using the AIC and BIC values as a guidance, I choose the log-normal over the other three models. In the subsequent analysis, I will base my main inference on the log-normal model represented below:

$$\tau_j = e^{-x_j\beta} t_j \tag{11}$$

where $\tau_j \sim Lognormal(\beta_0, \sigma)$ and t_j is time at risk for the jth event's time (days) to each event from the time of the previous event. The associated cumulative distribution is given by:

$$F(t_j|x_j) = \Phi(\frac{lnt_j-(\beta_0+x_j\beta)}{\sigma}) \tag{12}$$

The survival function can be expressed as:

$$S(t_j|x_j) = 1 - \Phi(\frac{lnt_j-(\beta_0+x_j\beta)}{\sigma}) \tag{13}$$

To interpret β, equation (4) can be written as

$$lnt_j = \beta_0 + x_j\beta + u_j \tag{14}$$

where $u_j \sim N(0, \sigma)$.

Hence, the expected time to failure can be expressed as

$$E(t_j|x_j) = e^{\beta_0} e^{x_j\beta} \tag{15}$$

In equation (9), a one-unit increase in any element k in the vector x_j thus induces the time to failure to increase by the factor e^{β_k}. That is, every one unit change in x_j corresponds to a change of $100 \times [1 - \exp(\hat{\beta}_k)]$ percent in the expected survival time. The effect of the covariate on the response is to either accelerate ($\hat{\beta}_k < 0$) or decelerate ($\hat{\beta}_k > 0$) the failure time.

3.16 Bayesian Analysis

The second robustness check outlined in Appendix 3 moves away from the assumptions of the frequentist approach and seeks to examine whether the findings remain robust under Bayesian statistics. The Bayesian hypothesis testing approach relies on the estimation of probability for a parameter of interest. For my application, the most significant advantage is that given the observed data, the Bayesian hypothesis testing can estimate the probability of how likely the parameters of interest fall within any predetermined range of values. This ability to assign a probability to a hypothesis is more flexible compared to the deterministic approach of the conventional frequentist hypothesis testing based upon the obtained p-value adopted earlier. Unlike the previous two sets of analyses based on the frequentist approach, Bayesian hypothesis testing provides direct estimation of the following questions: What is the probability that the hazard of piracy attack increases when there are 1) Motivated offenders; 2) Absence of capable guardian; 3) Suitable targets; and 4) Convergence of these three ingredients. I argue that the robustness check based on Bayesian statistics is appropriate because frequentist hypothesis testing obviously cannot be relied upon to answer these questions. Because the conclusions drawn from the Bayesian analyses are not distinct from those of the main estimation strategies, I choose to include them in Appendix 3 instead of the main text.

<Insert Appendix 3>

Summing up this section, I lay out the series hazard model after operationalizing the key dependent and independent variables. Because the multiple robustness checks do not give a different conclusion compared with the main model, I included them in the Appendix 3 instead. The data and estimation strategies for R3 are discussed next.

R3) To what extent do economic conditions of fishermen impact the instantaneous risk of piracy in East Africa and South East Asia?

For the third research question R3, I first introduce the sources of my data before operationalizing the dependent variable. Next, I defend the use of the weather-shock approach as an instrument for economic conditions of the fishermen. Key independent variables and controls are then operationalized, before I lay out the analytical plan of the structural equation models for hazard functions. The identifying assumptions are then checked to ensure that the analytical model is valid. As explained previously, I choose to include the robustness check in Appendix 4 instead of the main text because it does not offer a different set of conclusions compared to the main analytical model.

For the following survival analyses, I analyze 1,049 pirate attacks in the Gulf of Aden from 2002 to 2013 and 1,834 pirate attacks in Malacca Strait and South China Sea combined from 1995 to 2007. The fishery data are obtained from the FishStatJ software developed by the Food and Agricultural Organization of the United Nations. The time-series for fish capture production (in 100,000 tons) for all types of fish species for each country is recorded. The Sea Surface Temperature (SST) data are obtained from the National Centers for Environmental Information. I provide detailed explanation on how these two data sources are operationalized for my research below. The semiparametric additive hazards model is used as the main estimation strategy. A robustness check using an alternative specification is presented in Appendix 4.

To measure the impact of economic conditions on the risk of piracy in East Africa and Malacca Strait and South China Sea combined, I instrument the endogeneous variable “Fish Capture Production” with the variation of the Sea Surface Temperature (SST) as a source of shock exogeneous to the risk of piracy in these two regions. In the following sub-sections, I first discuss why using SST is an appropriate instrument for fish capture production. Next, I show how the instrument is constructed. Last, I demonstrate the operationalization of the independent variable and the list of controls using the case of East Africa.

3.17 Dependent Variable

Similar to the dependent variable described in R2, the dependent variable adopted here is also "Days Until Next Attack". In East Africa, the first attack occurred on January 4, 2002 and this date was set to be the time origin as it marks the onset of continuous exposure to risk of piracy attack in the data set. This criterion excludes the earlier period (January 1st, 2002 to January 3rd, 2002) when the hazard of piracy is necessarily zero.

3.18 Instrumental Variable

As demonstrated in the previous chapter, prior studies had not adequately address the endogeneity of economic variables to piracy and for those that relied on an instrument, the choice of the instrument is not defensible. Here, I argue that by relying on fluctuations in the Sea Surface Temperature (SST), an exogenous source of variation with respect to fish capture production, the impact of economic conditions on the hazard of pirate attacks can be estimated in a defensible way. This means that the problematic endogeneity issue (between the risk of attacks, y_i, and fish output x_i can be ameliorated). By instrumenting fish output with changes in SST, I also avert measurement issues related to fish catches. Based on previous studies that used weather-shock as instruments, I justify the validity of the choice of the instrument and argue that it is uncorrelated with the error term (u_i). By using a weather-shock approach, both the observed and unobserved effects of the instrument on y_i can be eliminated. Moreover, the weather-shock approach enables me to eliminate any reverse effect of y_i on the instrument. The following flow chart provides a summary of the relationship:

$$\begin{tikzcd} \textit{SST standard deviations } (z_{il}) \arrow[r] & \textit{Fish production } (x_i) \arrow[r] & \textit{Piracy Attacks } (y_i) \\ & u_i \arrow[u] \arrow[ur] & \end{tikzcd}$$

Note: z_{il} uncorrelated with u_i but correlated with x_i

The variable SST serves as the instrument to tease apart the endogeneity between fish output and risk of piracy for my analysis. To capture the long term SST changes for the study area, I derive variations from the National Oceanic and Atmospheric Administration's (NOAA) Extended Reconstructed Sea Surface Temperature data, available at a resolution of 1°x1° and containing the monthly mean SST data. I aggregate the data from 1970 to 2014 into geospatially referenced grid cells using ArcGIS. To measure the long term SST variation across the East of Africa, I design a polygon shape file covering the western half of the Indian Ocean bordering Africa, the Middle East, and South Asia (from 22° to 68° longitude). The decision to include such a large study area was animated by a desire to capture a large range and distribution of piracy incidents across the regions, which a more selective and constrained geographic focus would fail to capture. With only two exceptions in which the coordinates were erroneously coded in the database, the study area captured all of the cases listed under "Geographic area of incident – East Africa" and "Incident data between 2002-01-01, 2013-12-31" in the IMO-GISIS database.

In order to best measure long term SST changes, I focus on aggregating the monthly mean SST data though the 45-year period of the analysis, and create a standard deviation (SD) for each month's mean temperature through the years. Next, I select all of the 1°x1° grid cells which intersected with the polygon shape file, and remove those with null temperature values (i.e. those occurring mostly over land). I then combine all of the grid's individual temperature values by month into an aggregate monthly value for the region. I then proceed to take the average of each month of every year, and develop 12 monthly mean SST sets and standard deviations for the study area. From this point, I am able to look at the monthly variations in the SST controlling for seasonal variations from 2002 to 2013. Therefore, the measure SST is operationalized as the number of standard deviations from the sample standard deviation, or mathematically:

$$\# \; of \; STDEV = \frac{SST_i - \overline{SST}}{Sample \; STDEV}, i = 2002 \ldots 2013$$

According to Table 4, the mean of the variable SST is 0.909, with a minimum and maximum value of -0.574 and 2.109.

<Insert Table 4>

<u>*3.19 Independent Variable*</u>

The independent variable is "Fish Capture Production", which measures the yearly total weight (100,000 tons) of all types of fish captured by each of the littoral countries in the East Africa region in the Western Indian Ocean: Eritrea, Kenya, Madagascar, Somalia, Tanzania and Yemen and reported to the Food and Agricultural Organization of the United Nations. It is measured at the time of each attack. The mean of the series is 6.076 with a minimum and maximum value of 5.017 and 6.546 as displayed in Table 4.

3.20 Controls

The variable “Regional Misery Index” is computed as the sum of the yearly inflation and unemployment rates in each of the littoral countries in the East Africa region as listed earlier. The Regional Misery Index is taken at the time of each attack. Table 4 shows that the mean of the series is 94.775, with a minimum and maximum value of 66.628 and 117.354. Next, the variable “Regional Trade” is operationalized as the cumulative value of trade passing through the region on a quarterly basis during the study period. The cumulative trade is measured as the sum of export (fob) plus import (cif) from 1) Asia-Europe, 2) Oceania-Europe, 3) Middle East-Europe, and 4) East Africa-Europe. The mean of the series is 2.445. The dichotomous variable “Merchant Ships” is coded as “1” if the ship type is a container ship, cargo ship or tanker and “)” otherwise. The contextual variables “Success Density” and “Last Reported” are coded similarly as described earlier, and their means are 18.604 and 0.817, respectively, as shown in Table 4.

3.21 Structural Equation Models for Hazard Functions

Structural equation models (Bollen, 1989; Weston and Gore, 2006) are a popular tool among econometricians for addressing unmeasured confounding in which the instrumental variable (IV) serve as an exogenous source of variation in the treatment under study (Angrist, 2006; Angrist and Krueger, 2001; Angrist and Pischke, 2008). Bushway and Apel (2010) noted that the classic use of IV methods in criminological research is treatment effect estimation in randomized trials and non-experimental studies with selection bias, simultaneity and measurement error. In the criminological and criminal justice literature, most of the applications of IV methods are based on two-stage least square estimation of structural equation models that are linear and specified for discrete or continuous outcomes (Apel et al., 2008; Kirk, 2009; Levitt, 1996; Spelman, 2008; Tita et al., 2006). However, to the best of my knowledge, there is a scarcity of research extending IV methods to time-to-event criminological problems. Recently, epidemiologists have developed the IV approach for regression analysis in a survival context, using the additive hazards model and the proportional hazards model (Li et al., 2014; Tchetgen et al., 2015). I adapt the two-stage IV method proposed by Li et al. (2014) and formulate structural equations models below.

Using the semiparametric additive hazards model conditional on the covariate *X*, the hazard function of the survival time *T* satisfies:

$$h\left(t;\ X_{Fish}, X_{Misery}, X_{Trade}, X_{Merchant}, X_{Context}, X_u\right) = h_0(t) + \beta_{Fish} X_{Fish} + \beta_1^T X_{Misery} + \beta_2^T X_{Trade} + \beta_3^T X_{Merchant} + \beta_o^T X_{Context} + \beta_u^T X_u \qquad (16)$$

where X_{Fish} is an endogenous variable for fish capture production, X_{Misery}, X_{Trade}, $X_{Merchant}$ and $X_{Context}$ are the vector of observed exogenous covariates, and X_u is a q-vector of unobserved explanatory variables that are correlated with X_{Fish}.

The baseline survival function given only the endogenous variable and the vector of observed exogenous covariates can then be expressed as:

$$S\left(t;\ X_{Fish}, X_{Misery}, X_{Trade}, X_{Merchant}, X_{Context}\right) = S_0(t)\exp\{-t\left(\beta_{Fish} X_{Fish} + \beta_1^T X_{Misery} + \beta_2^T X_{Trade} + \beta_3^T X_{Merchant} + \beta_o^T X_{Context}\right)\} \times \int \exp\{-t\beta_u^T X_u\} dF(X_u | X_{Misery}, X_{Trade}, X_{Merchant}, X_{Context}) \quad (17)$$

Given that X_{Fish} is confounded by X_u, the effect of X_{Fish} on the survival probability may still enter (17). As a result, fitting the model

$$h\left(t;\ X_{Fish}, X_{Misery}, X_{Trade}, X_{Merchant}, X_{Context}\right) = h_0(t) + \gamma_{Fish} X_{Fish} + \gamma_1^T X_{Misery} + \gamma_2^T X_{Trade} + \gamma_3^T X_{Merchant} + \gamma_o^T X_{Context} \quad (18)$$

will lead to the estimator of $\tilde{\gamma}_{Fish}$ being inconsistent.

I next utilize the standard specification for the endogenous variable in IV estimation (Bollen, 1989) in order to obtain a consistent estimator for β_{Fish}:

$$X_{Fish} = \alpha_C + \alpha_{SST} X_{SST} + \alpha_1^T X_{Misery} + \alpha_2^T X_{Trade} + \alpha_3^T X_{Merchant} + \alpha_o^T X_{Context} + \alpha_u^T X_u + \epsilon \quad (19)$$

where α_C is the coefficient for the constant intercept, α_{SST} is the coefficient for the instrumental variable, α_1, α_2, α_3 are the coefficients for the observed exogenous variables, and α_u is the coefficient for the unobserved confounders. Under the IV conditions A1-3 described in the following sub-section, β_{Fish} can be estimated by coupling (18) and (19) according to the following steps:

Fit the linear model for X_{Fish} on X_{SST} and $X_{Misery}, X_{Trade}, X_{Merchant}, X_{Context}$ to obtain ($\tilde{\alpha}_C, \tilde{\alpha}_{SST}, \tilde{\alpha}_{Misery}^T, \tilde{\alpha}_{Trade}^T, \tilde{\alpha}_{Merchant}^T, \tilde{\alpha}_{Context}^T$)

1) Compute the predicted value of $\tilde{X}_{Fish} = \tilde{\alpha}_C + \tilde{\alpha}_{SST} X_{SST} + \tilde{\alpha}_{Misery}^T X_{Misery} + \tilde{\alpha}_{Trade}^T X_{Trade} + \tilde{\alpha}_{Merchant}^T X_{Merchant} + \tilde{\alpha}_{Context}^T X_{Context}$
2) Denote C as the censoring time such that $Y_i = \min(T_i, C_i)$, $\Delta_i = I(T_i \leq C_i)$ and $\{X_{Fishi}, X_{Miseryi}, X_{Tradei}, X_{Merchanti}, X_{Contexti}, i = 1, \ldots, n$. Assuming that C is conditionally independent of T given X_{SST} and $X_{Misery}, X_{Trade}, X_{Merchant}, X_{Context}$, the coefficient for $\tilde{X}_{Fish}$ in the second stage is a consistent estimator for β_{Fish}.
3) With known $\alpha_C, \alpha_{SST}, \alpha_{Misery}, \alpha_{Trade}, \alpha_{Merchant}, \alpha_{Context}, \alpha_u, \beta_{Fish}$ in (19) may

be replaced with (19). The conditional survival function given

$\tilde{X}_{Fish}, \epsilon, X_{Misery}, X_{Trade}, X_{Merchant}, X_{Context}, X_u$ can then be expressed as:

$$S\left(t;\ \tilde{X}_{Fish}, X_{Misery}, X_{Trade}, X_{Merchant}, X_{Context}\right) = S_0(t)\exp\left\{-t\left(\beta_{Fish}\tilde{X}_{Fish} + \beta_1^T X_{Misery} + \beta_2^T X_{Trade} + \beta_3^T X_{Merchant} + \beta_o^T X_{Context}\right)\right\} \times \int \exp\{-t(\beta_{Fish}\alpha_u^T + \beta_u^T)X_u - t\beta_{Fish}\epsilon\} dF(\epsilon, X_u) = S_0(t)\int \exp\{-t(\beta_{Fish}\alpha_u^T + \beta_u^T)X_u - t\beta_{Fish}\epsilon\} dF(\epsilon, X_u)\exp\left\{-t\left(\beta_{Fish}\tilde{X}_{Fish} + \beta_1^T X_{Misery} + \beta_2^T X_{Trade} + \beta_3^T X_{Merchant} + \beta_o^T X_{Context}\right)\right\} \quad (20)$$

4) $S_0^*(t) = S_0(t)\int \exp\{-t(\beta_{Fish}\alpha_u^T + \beta_u^T)X_u - t\beta_{Fish}\epsilon\} dF(\epsilon, X_u)$ (21)

is denoted as the modified baseline survival function that does not involve

$\tilde{X}_{Fish}, X_{Misery}, X_{Trade}, X_{Merchant}, X_{Context}$.

3.22 Identifying Assumptions

The identifying assumptions that must be met in order to establish the validity for Equation (21) are:

A1) The factors determining the SST are exogenous to other factors influencing the hazard of piracy. That is, if X_{SST}, X_u, X_{Misery}, X_{Trade}, $X_{Merchant}$ and $X_{Context}$ are mean zero variables, the error term ϵ is assumed to have $E(\alpha_u^T X_u + \epsilon | X_{SST}, X_{Misery}, X_{Trade}, X_{Merchant}, X_{Context})=0$.

The plausibility of the three assumptions are presented below. For A1, the variation of SST is the result of a complex interaction of factors such as wind patterns and the regional geographical characteristics, as well as by global thermohaline circulation (Clark et al. 2002; Latif et al. 2004; Stolpe, Medhaug and Sedlacek, 2018). Therefore, I argue that the regional SST variations in the Horn of Africa and South China

Sea can be regarded as exogenous to the correlates of piracy. Moreover, I center the means of the variables $X_{SST}, X_u, X_{Misery}, X_{Trade}, X_{Merchant}$ and $X_{Context}$ in the subsequent analysis.

A2) SST affects the fish output production. That is, $\alpha_{SST} \neq 0$ conditional on the vector of observed exogenous covariates.

Regarding A2, changes in the SST should only influence the hazard of piracy via the variation induced in the fish capture production in order for the instrumental variable approach to yield unbiased estimates. This assumption may be violated under the following circumstances. The passing of a hurricane can induce variation in SST (Schade, 2000; Lloyd and Vecchi, 2011), as well as changes in the routine activity of the pirates, which in turn could induce variation in the hazards of piracy. However, I expect events such as these that might potentially compromise the internal validity of the research design to be extremely rare and that SST is largely uncorrelated with these individual local factors.

A3) Changes in SST only affect the hazard of piracy through the variation induced in the fish output production. That is, X_{SST} is independent of (T, X_u) conditional on X_{Misery}, X_{Trade}, $X_{Merchant}$ and $X_{Context}$.

For A3, it means that the spatial-temporal variation in the SST causes variation in the fish capture production. I report OLS regression output estimates to assess the validity of this assumption in the following chapter.

<u>*3.23 Robustness Check*</u>

Unlike the additive model that estimates the difference in hazards, the proportional hazards model estimates hazard ratios. To enhance confidence in the results, I resort to an alternative method - instrumental variable Cox proportional hazards models, as a robustness check. The coefficients of the model and their interpretation are reported in Appendix 4.

3.24 Chapter Summary

The first part of the Data and Methods section introduces the IMO-GISIS database that I rely on for the dissertation. I presented the summary statistics of the trend of the attacks regions of interest. For the first research question, I outlined the procedures for performing the optimized hot spot analysis, emerging hot spot analysis, and local outlier analysis for both crime count and harm to assess the degree of crime concentration at places. In the second research question, I tested the routine-activities perspective using the series hazard model and ensure that the conclusions drawn are valid by conducting several robustness checks. Last, the semiparametric additive hazards model is used as the main estimation strategy for the third research question testing the rational-choice theory. The results for these three research question will be reported in the next chapter Results, and their value-addedness to criminological theories, methods and policy will be discussed in the final chapter.

Chapter 4: Results

In this chapter I present results and their statistical interpretation for the modeling approaches employed to test the three research questions outlined in the previous chapter. I start off in 4.1 with the discussion of the worldwide and regional trends of piracy attacks and harm. For the first research question R1, using geo-coordinates two types of analysis (frequency versus harm) at three spatial levels (worldwide, East Africa, Malacca Strait and South China Sea combined) are performed to show the concentration of crime and harm at places. The results for the optimized hot spot analysis, inverse distance weighting interpolation, space time cube, emerging hot spot analysis and local outlier analysis of both attacks and harm for worldwide and two regions - East Africa, Malacca Strait and South China Sea combined are examined in 4.2 to 4.4. Additionally, I analyze the concentration of frequency and harm at the grid level for piracy attacks worldwide in 4.5.

To tackle the second research question R2, I first present the temporal distribution of pirate attacks in the Malacca Strait and South China Sea in 4.6. Next, three distinct types of analysis are performed to test Hypotheses (1) to (4) and as robustness checks to ensure that the results possess a high degree of internal validity. I analyze whether each of the measures of motivation and suitable target is positively related to the hazard of piracy attacks, and whether each of the measures of absence of capable guardian is positively related to the hazard of piracy attacks, holding all other variables constant in 4.7. As discussed in Chapter 2, I also examine whether the convergence of motivation, absence of capable guardians and suitable target comports with the prediction of routine activity theory to affect the hazard of piracy attacks in 4.8. I perform two robustness checks to maximize confidence in the results – 1) I examine the proportional hazard assumption of the Cox model in section 4.9; 2) I rely on an alternative survival function – the accelerated failure time model – to ascertain the findings in 4.10. To ensure robustness, I rely on a Bayesian accelerated failure time model in 4.11 to compute the posterior probability that the hazard of piracy attack increases under Hypotheses (1) to (4). The frequentist's approach[xxv] adopted in steps 1 and 2 does not allow me to make such statements because it treats the hazard of pirate attack as simply an unknown constant which either lies in a certain range or does not. In this sense, the Bayesian approach is more flexible because it allows policy makers to make probability statements on the risk of pirate attacks, rather than simply providing a dichotomy (i.e., reject or does not reject a null hypothesis based on a given p-value). The final robustness check is presented in Appendix 3 given that they point to the same direction as the main analytical model.

For R3, Hypothesis 5 is tested using the instrumental variable estimation in a survival context. In 4.12, I first perform OLS regressions to show that the instrument variable SST is associated with fish capture production, conditional on the remaining terms. Next, in 4.13 I use semiparametric additive hazards models with the control variables to estimate the impact of fish capture production on the duration of maritime piracy. I then quantify the effect of variation in SST on the instantaneous risk of piracy in terms of fish capture production by instrumenting the endogenous variable fish capture production with the SST measure. To enhance confidence in the results, I repeat the analysis using an IV Cox proportional hazards model in 4.14 and the results are shown in

Appendix 4 because they offer the same conclusion compared to the main estimation strategy. 4.15 concludes the chapter

R1) To what extent does environmental criminology, crime pattern theory and crime concentration at places improve our understanding of maritime piracy?

For the first research question R1, I perform an inductive exploration by attempting to find out from a large geodatabase of pirate attacks whether there is any statistically significant patterns of spatial, as well as spatial-temporal, concentration of crime and harm. Results for the spatial-temporal clustering of piracy attacks and harm worldwide, in Malacca Strait and South China Sea, and East Africa indeed support the argument that there exist statistically significant clustering patterns. Similar conclusions are reached for the concentration of frequency and harm at the grid level for piracy attacks worldwide. I use the term "power-few" in this section to refer to a small proportion of "space-time bins" or grids that are responsible for a huge proportion of all attacks and harm.

4.1 Temporal Trends in Maritime Piracy

The time-series of pirate attacks exhibited in Figure 1 shows the trends in piracy for four regions - worldwide, South China Sea, East and West Africa - from 1994 to 2017. Overall, it can be seen that worldwide pirate attacks can be decomposed into two main waves with each lasting about a decade. The first wave was tightly coupled to the trend in pirate attacks in the South China Sea. It started at the beginning of the series, reaching its first crest of 492 attacks in the year 2000, declined during the period 2000 to 2003, before reaching its second peak of 451 attacks in the year 2003. From 2003 to 2006, global pirate attacks experienced a 45 percent drop chiefly driven by the decline in

South East Asia. The first wave ended in the year 2006 reaching a trough of around 246 attacks. Correspondingly, the trend of pirate attacks in the South China Sea shared a similar pattern. It reached its first crest of 146 attacks in the year 2000, fluctuated during 2003 to 2006, before attaining its second crest of 152 attacks in 2003. During the next three years, the frequency dropped from 152 to 66, or 57 percent, mainly due to joint naval patrol interventions started in 2004 by the Royal Malaysian Navy, Republic of Singapore Navy and the Indonesian Navy. The amplitude for the first global wave is 246 attacks while that of South China Sea is 80. During the first wave, the proportion of attacks perpetuated in South China Sea to attacks worldwide averaged 38 percent, while that for East and West Africa averaged 7 and 12 percent, respectively. Recently, the South China Sea experienced a drop in the number of attacks. The share of attacks committed in the region fell to approximately 17 percent of the worldwide total in 2009, compared to 53 percent at its peak.

<Insert Figure 1>

Turning to the other activity node of East Africa, Figure 1 clearly shows that the genesis of the second wave of worldwide pirate attacks coincided with the upward trajectory of attacks in East Africa. From 2006 to 2011, the number of pirate attacks worldwide increased from 246 to 570 (a 131 percent increase) while that of East Africa spiked from 31 to 238 (a 668 percent increase). The proportion of attacks perpetuated in East Africa to attacks worldwide spiked from around 12 percent in 2006 to approximately 54 and 42 percent in the years 2009 and 2011, respectively. The decline in pirate attacks in East Africa declined after 2011, as a result of a combination of joint international naval patrols and active intervention of armed private security company (PSC) guards carried onboard ships transiting the region. Within three years, it dropped to only 3 attacks or around 1 percent of global attacks, and remained so till the end of the series. Consequently, worldwide attacks declined by 49 percent.

As described earlier I calibrate the harm of each attack reported to the IMO and plot the time series for the mean harm of worldwide attacks between 2006 and 2014. From 2006 to 2011, the trend of the mean harm of attacks decreased while that of the frequency of attacks increased. The mean harm is 2,711 Cambridge Harm Index (CHI) prison days in 2006, rose to 3,348 the next year, before gradually declining to 2,444 CHI prison days in 2011. From 2011 to 2014, the mean harm value increased by 24 percent while the frequency of attacks dropped by 49 percent. One possible explanation is that the high-volume, low CHI value pirate attacks (such as burglary or harassment) dropped, while the low-volume, high CHI value pirate attacks (such as hijackings) increased. Figure 1 shows that the temporal variations of frequency and harm may differ. In fact, they moved in opposite directions during certain periods of time. For instance, the worldwide mean CHI decreased from 2006 to 2008, while the worldwide attack frequency increased. Also, the worldwide mean CHI reached a trough of 2,444 CHI prison days while the worldwide attack frequency reached a peak of 516 attacks. From 2011 to 2014, worldwide attack frequency decreased 60 percent while the worldwide mean CHI increased 24 percent. This simple descriptive analysis goes to show that for the case of piracy, the time trends of the frequency and mean harm of attacks do not move in tandem. Therefore, the set of policies that are targeted to reduce the count of pirate attacks might not be effective towards harm reduction.

4.2 Results for Spatial-Temporal Clustering of Piracy Attacks and Harm Worldwide

The minimum, maximum, mean and standard deviation of attacks is 1, 53, 2.15 and 4.14, respectively. For the scale of analysis, I look for an optimal scale of analysis by assessing the intensity of clustering at increasing distance. Based on my estimation the optimal fixed distance band is based on peak clustering found at 743,513.18 meters. In the hot spot analysis of statistically significant clustering of high and low incident counts, I find that there are 588 output features statistically significant based on the false discovery rate correction for multiple testing and spatial dependence. 6.1 percent of features had less than 8 neighbors based on the optimal distance band.

In Figure 2A, the red output features represent hot spots where high attack values (Z-score) cluster. They are mostly clustered along the Malacca Strait and South China Sea, near the port of Chittagong and port of Kuakata of Bangladesh, port of Yangon in Myanmar, port of Luanda and port of Lobito in Angola, port of Lima in Peru, and near the coast of Colombia and Panama. On the other hand, the blue output features represent cold spots where low attack values (Z-score) cluster. They are mostly clustered along the Arabian Sea, as well as the coasts of Oman, Yemen, Somalia, Kenya and Tanzania. In Figure 2B, I rely on the IDW to predict the values of interpolated attacks. The hot spots of attack are predicted to be most strongly concentrated along the Malacca Strait and South China Sea, as well as the coasts of Bangladesh and Myanmar. Conversely, the cold spots of attacks are predicted to be cluster mostly around the Arabian Sea, and the international water off Kenya.

<Insert Figure 2A>

<Insert Figure 2B>

Next, I create the space time cube for piracy attacks worldwide to study the spatial temporal concentration of attacks and harm. The results indicate that it aggregated 2,563 points into 5,000 fishnet grid locations over 17 time step intervals. Each location is a 231,233 meters by 231,233 meters square. The entire space time cube spans an area 23,123,300 meters west to east and 11,561,650 meters north to south. Each of the time step intervals is 6 months in duration so the entire time period covered by the space time cube is 102 months. Of the 5000 total locations, 341 (6.82 percent) contain at least one point for at least one time step interval. These 341 locations comprise 5,797 space time bins of which 1,073 (18.51 percent) have point counts greater than zero. There is not a statistically significant increase or decrease in point counts over time (Trend statistics S=1.442 and p=0.149).

After I generated the space time cube, the distribution of hot spots is illustrated in Figure 2C. Compared to the rest of the 341 locations, there is statistically significant evidence to show clustering of hot spots along the Malacca Strait and South China Sea. Specifically, there are 19 consecutive hot spots, meaning that in those 19 locations there is a single uninterrupted run of hot time step intervals during less than 90 percent of the 17 intervals. There are 5 diminishing hot spots in the same region which implies that in those 5 locations at least 90 percent of the 17 time step intervals are hot, but over time the intensity is decreasing.

<Insert Figure 2C>

The local outlier analysis indicates that out of a total of 341 locations, there are 9 locations that comprise only high-high (HH) clusters, 16 locations that comprise of only low-high (LH) outlier, 87 locations that comprise of only low-low (LL) cluster, 43 locations that only comprise of high-low outlier (HL), and 110 locations that comprise of multiple types. Four of the HH clusters shown in pink in Figure 2D are located in the Malacca Strait and South China Sea, one off the coast of Bangladesh, two along the Gulf of Aden, and two in the Gulf of Guinea. These nine only HH locations which comprise of 2.64 percent of all locations are the most policy relevant "power-few" for targeting because the concentration of attacks within the bins in these locations is higher than other bins, and the concentration of attacks within the bins' neighborhoods in these locations is higher than other neighborhoods.

<Insert Figure 2D>

The next set of analysis relates to the harm associated with attacks for piracy attacks worldwide. The minimum, maximum, mean and standard deviation of harm is 10, 17,721, 2,862.45 and 3,844.05, respectively. For the scale of analysis, I look for an optimal scale of analysis by assessing the intensity of clustering at increasing distance. Based on my estimation the optimal fixed distance band is based on peak clustering found at 540,880.14 meter. In the hot spot analysis of statistically significant clustering of high and low harm values, I find that there are 2131 output features statistically significant based on the false discovery rate correction for multiple testing and spatial dependence. 2.2 percent of features had less than 8 neighbors based on the optimal distance band.

<Insert Figure 3A>

<Insert Figure 3B>

<Insert Figure 3C>

<Insert Figure 3D>

The optimized hot and cold spot analysis of harm for piracy attacks worldwide is shown in Figure 3A. The red output features that represent hot spots where high harm values (Z-score) cluster are dispersed along the Malacca Strait and South China Sea, near the port of Lima in Peru, and near the coast of Colombia and Panama. The blue output features that represent cold spots where low harm values (Z-score) cluster are mostly concentrated along the Arabian Sea, as well as the coasts of Oman, Yemen, and Tanzania. Comparing Figure 2A with Figure 3A in terms of hot and cold spots, some interesting findings emerged. The Gulf of Guinea and the West Indian Ocean which were previously non-significant under the frequency hot spot analysis have now gained significance in the harm hot spot analysis. Interestingly, the port of Chittagong and port of Kuakata of Bangladesh which were significant hot spots of frequency have turned into significant cold spots of harm, while the port of Yangon in Myanmar which was a significant hot spot has lost its significance in the harm hot spot analysis. On the other hand, the attacks off the coasts of Sierra Leone and Liberia which were non-significant under the frequency hot spot analysis have now turned into significant harm hot spots, while the attacks off the coast of Vietnam which were non-significant under the frequency hot spot analysis have now turned into significant harm cold spots. These striking differences are also evident in the visual comparison of Figure 2B and 3B which shows the predicted values of interpolated attacks based on inverse distance weighting.

Using the space time cube for the harm of piracy attacks worldwide, the estimated value for the trend statistics S is 1.936 and the p value is 0.053. I conclude that there is statistically significant evidence to show that harm is increasing over time. After the space time cube is generated, the distribution of hot spots of harm is illustrated in Figure

3C. Compared to the rest of the 341 locations, there is significant evidence to show clustering of hot spots along the Malacca Strait and South China Sea, as well as the Gulf of Guinea. Compared to the frequency analysis, the number of consecutive hot spots of harm drops to 14. The number of diminishing hot spots drops to zero while the number of sporadic hot spots of harm increases to 17. Comparing Figure 2C and 3C, four sporadic hot spots of harm and one consecutive hot spot of harm emerge in the Gulf of Guinea.

The local outlier analysis of harm indicates that out of a total of 341 locations, there are 3 locations that comprise only high-high (HH) clusters, 13 locations that comprise only low-high (LH) outliers, 151 locations that comprise only low-low (LL) clusters, 21 locations that only comprise high-low outliers (HL), and 57 locations that comprise multiple types. The visual comparison of Figure 2D and Figure 3D suggests that the HH cluster located in the Singapore Strait appears both in the frequency and harm local outlier analysis. This suggests that the concentration of attacks and harm within the bins in the Singapore Strait is higher than other bins, and the concentration of attacks and harm within the bins' neighborhoods covering the Singapore Strait is higher than other neighborhoods. The policy implication of this important finding will be elaborated in the final chapter.

4.3 Results for Spatial-Temporal Clustering of Piracy Attacks and Harm in East Africa

For East Africa, the minimum, maximum, mean and standard deviation of attacks is 1, 33, 2.30 and 3.53, respectively. For the scale of analysis, I look for an optimal scale of analysis by assessing the intensity of clustering at increasing distance. Based on my estimation the optimal fixed distance band is based on peak clustering found at 975,912.96 meters. In the hot spot analysis of statistically significant clustering of high and low incident counts, I find that there are 348 output features statistically significant based on the false discovery rate correction for multiple testing and spatial dependence. 1.7 percent of features had less than 8 neighbors based on the optimal distance band.

In Figure 4A, the red output features represent hot spots where high attack values (Z-score) cluster. They are mostly clustered along the coast of Somalia, Yemen, Djibouti, Eritrea and Gulf of Aden. On the other hand, the blue output features which represent cold spots where low attack values (Z-score) cluster are mostly dispersed along the international water in the region. The values of interpolated attacks shown in Figure 4B indicates that the hot spots are most strongly clustered along the Gulf of Aden, while the cold spots are concentrated along the Arabian Sea, and the international water off the coast of Kenya and Tanzania.

<Insert Figure 4A>

<Insert Figure 4B>

To study the spatial temporal concentration of attacks and harm within East Africa, I rely on the space time cube. The space time cube has aggregated 1,083 points into 3,800 fishnet grid locations over 17 time-step intervals. Each location is a 101,247 meters by 101,247 meters square. The entire space time cube spans an area 3,847,386 meters west to east and 10,124,700 meters north to south. Each of the time step intervals is 6 months in duration so the entire time period covered by the space time cube is 102 months. Of the 3800 total locations, 392 (10.32 percent) contain at least one point for at least one time step interval. These 392 locations comprise 6664 space time bins of which 671 (10.07 percent) have point counts greater than zero. The value of the MK trend statistic is estimated to be -0.247 and its p value is 0.8046. The overall data trend shows that there is no statistically significant change in point counts over time.

In the emerging hot spot analysis, the distribution of hot spots is illustrated in Figure 3C. Compared to the rest of the 392 locations, there is significant evidence to show clustering of three new hot spots off the coast of the Gujarat region, India. This means that these three location were not hot for the first 16 time step intervals. They become hot for the first time during the last time step interval from June 2014 to December 2014. No other types of hot spots are found. In the local outlier analysis of 392 locations, I find 1 location of only high-high (HH) clustering, 9 locations that comprise of only low-high (LH) outlier, 83 locations that comprise of only low-low (LL) cluster, 25 locations that only comprise of high-low outlier (HL), and 157 locations that comprise of multiple types. The HH location which lies in the Gulf of Aden is surrounded by multiple type locations. Given that the concentration of attacks within the bins in the Gulf of Aden is higher than other bins, and the concentration of attacks within the bins' neighborhoods in Gulf of Aden is higher than other neighborhoods, the location which measures 101,247 meters by 101,247 meters should become the target for intensive policing. On the contrary, policing resources should be reduced in the LL locations which are mainly dispersed in the international water south of the Arabian Sea because the concentration of attacks within the bins in these areas is higher than other bins, and the concentration of attacks within the bins' neighborhoods in the same area is higher than other neighborhoods.

<Insert Figure 4C>

The harm associated with attacks for piracy attacks in East Africa is examined next. The minimum, maximum, mean and standard deviation of harm is 10, 17,703, 1,953.75 and 3,272.80, respectively. For the scale of analysis, I look for an optimal scale of analysis by assessing the intensity of clustering at increasing distance. No optimal distance is found using this method. To determine an optimal distance using the spatial distribution of feature, I find that the optimal fixed distance band is 271,929 meter. It is based on the average distance to 30 nearest neighbors. In the hot spot analysis of statistically significant clustering of high and low harm values, I find that there are 683 output features statistically significant based on the false discovery rate correction for multiple testing and spatial dependence. 7.6 percent of features had less than 8 neighbors based on the optimal distance band.

In Figure 5A which shows the optimized hot spot analysis of harm in East Africa, the red output features represent hot spots where high harm values cluster, while the blue output features represent cold spots where low harm values cluster. According to this figure, there is statistically significant evidence to suggest that the cold spots of harm are concentrated along the Gulf of Aden; while the statistically significant hot spots are clustered in the international water of the West Indian Ocean south of the Arabian Sea as well as near the coast of Kerala, India. Comparing Figure 4B and Figure 5B, the differences in terms of the areas interpolated through the inverse distance weighting procedure are quite striking. First, the statistically significant hot spots of frequency clustered in the Gulf of Aden are statistically significant cold spots of harm. Second, the statistically significant cold spots of frequency which are clustered in the international water of the West Indian Ocean south of the Arabian Sea are statistically significant hot spot of harm. This observation suggests that in East Africa, there is an inverse relationship between quantity and quality of attacks. In the discussion section, I will elaborate on the policy implications for fighting piracy frequency versus piracy harm.

<Insert Figure 5A>

<Insert Figure 5B>

<Insert Figure 5C>

To conduct the emerging hot spot analysis and the local outlier analysis of harm I rely on the space time cube generated earlier. The MK trend statistic value S is estimated to be -0.618 and the p value is 0.537. Therefore, there is no statistical significant evidence to indicate that harm is changing over time. The emerging hot spot analysis of harm results show two new hot spots and two sporadic hot spots, near the coast of Gujarat and Karala, respectively, as depicted in Figure 5C. Interpreted together with Figure 4C, the coast of Gujarat become hot for the first time during the last time step interval from June 2014 to December 2014 in terms of both frequency and harm. The local outlier analysis of harm indicates that out of a total of 392 locations, there are 6 locations that comprise of only high-high (HH) cluster, 58 locations that comprise of only low-high (LH) outlier, 67 locations that comprise of only low-low (LL) cluster, 5 locations that only comprise of high-low outlier (HL), and 201 locations that comprise of multiple types. The visual comparison of Figure 4D and Figure 5D indicates that while there are three HH clusters in the local outlier analysis of harm located in the Gulf of Aden, there is one overlapping HH cluster between the local outlier analysis of frequency and harm. There is statistical significant evidence to show that the concentration of both frequency and harm in this 101,247 meters by 101,247 meters square bin is higher than other bins, and the concentration of both frequency and harm in the neighborhood of this bin is higher than in all neighborhoods. The identification of this power-few bin implies that the police should target additional resources at this location, instead of other types of outliers or clusters. I will return to consider the implications of this finding in the final chapter.

<Insert Figure 4D>

<Insert Figure 5D>

4.4 Results for Spatial-Temporal Clustering of Piracy Attacks and Harm in Malacca Strait and South China Sea

In the Malacca Strait and South China Sea, the minimum, maximum, mean and standard deviation of attacks is 1, 32, 2.38 and 3.47, respectively. For the scale of analysis, I look for an optimal scale of analysis by assessing the intensity of clustering at increasing distance. No optimal distance was found using this method. To determine an optimal distance using the spatial distribution of feature, I find that the optimal fixed distance band is 301,593 meter. It is based on the average distance to 17 nearest neighbors. In the hot spot analysis of statistically significant clustering of high and low incident counts, I find that there are 10 output features statistically significant based on the false discovery rate correction for multiple testing and spatial dependence. 16.3 percent of features had less than 8 neighbors based on the optimal distance band.

In Figure 6A, the hot spots where high attack values (Z-score) cluster are located along the Malacca Strait northwest of Singapore. On the other hand, there is one cold spot where low attack values (Z-score) cluster located along the South China Sea northeast of Singapore. The predicted values of interpolated attacks based on IDW are illustrated in Figure 6B.

<Insert Figure 6A>

<Insert Figure 6B>

The space time cube for Malacca Strait and South China Sea has aggregated 817 points into 6,000 fishnet grid locations over 17 time step intervals. Each location is a 59,148 meters by 59,148 meters square. The entire space time cube spans an area 3548,880 meters west to east and 5,914,800 meters north to south. Each of the time step intervals is 6 months in duration so the entire time period covered by the space time cube is 102 months. Of the 6,000 total locations, 144 (2.40%) contain at least one point for at least one time step interval. These 144 locations comprise 2,448 space time bins of which 387 (15.81%) have point counts greater than zero. The MK trend statistic value for count is estimated to be 3.958 and its associated p value is 0.000. There is a statistically significant increase in point counts over time.

The emerging hot spot analysis of frequency is shown in Figure 6C. The G_i^* and S estimation procedures found that compared to the 144 locations, 4 locations are categorized as consecutive hot spot and 32 locations are categorized as sporadic hot spot. The former are situated near the coasts of north east and south east Sumatra, while the majority of the latter are clustered in the South China Sea to the north east of Singapore. In the local outlier analysis of the same 144 locations, the G_i^* and S estimation procedures found 4 locations that comprise of only high-high (HH) cluster, 14 locations that comprise of only low-high (LH) outlier, 8 locations that comprise of only low-low (LL) cluster, 35 locations that only comprise of high-low outlier (HL), and 18 locations that comprise of multiple types. The four HH clusters shown in pink in Figure 4D are located in the South China Sea to the north east of Singapore. As before, these four HH only locations which comprise of 2.78 percent of all locations are the most policy relevant "power-few" for targeting because the concentration of attacks within the bins in these locations is higher than other bins, and the concentration of attacks within the bins' neighborhoods in these locations is higher than other neighborhoods.

<Insert Figure 6C>

Compared with Figure 6A, the policy implication derived from Figure 6D is the complete reverse. In Figure 6A, the optimized hot spots are clustered in the Malacca Strait to the north west of Singapore, whereas in Figure 6D, the HH only locations are concentrated in the South China Sea to the north east of Singapore. The result shown in Figure 6A is somewhat limited compared to Figure 6D because it is derived using the G_i^* statistics only without taking the time series into consideration. Therefore, the failure to incorporate both space and time simultaneously in the hot spot estimation procedure would lead to incomplete results and misguided targeting strategy.

<Insert Figure 6D>

The next set of analysis relates to the harm associated with attacks for piracy attacks in Malacca Strait and South China Sea. The minimum, maximum, mean and standard deviation of harm is 10, 17,721.75, 3,602.76 and 4,111.62, respectively. For the scale of analysis, based on my estimation the optimal fixed distance band is based on peak clustering found at 252,667.02 meters. In the hot spot analysis of statistically significant clustering of high and low harm values, I find that there are 312 output features statistically significant based on the false discovery rate correction for multiple testing and spatial dependence. 5.8 percent of features had less than 8 neighbors based on the optimal distance band.

Figure 7A which is an illustration of the optimized hot spot analysis of harm indicates that the hot spots of harm are clustered off the coast off Aceh, Indonesia, as well as Terengganu, and Sarawak, Malaysia; while the cold spots of harm are concentrated near the coasts of Ho Chi Minh City and Hanoi, Vietnam, as well as Jakarta, Indonesia and Manila, Philippines. A comparison of Figure 6B and 7B shows that the interpolated areas of hot spots of frequency and harm did not overlap with each other.

<Insert Figure 7A>

<Insert Figure 7B>

In the space time cube, the MK trend statistic value for harm is estimated to be 2.925 and its associated p value is 0.003. There is a statistically significant increase in harm over time. Figure 7C shows the emerging hot spot analysis of harm using this space time cube. The G_i^* and S estimation procedures found that compared to the 144 locations, 4 locations are categorized as consecutive hot spot of harm and 34 locations are categorized as sporadic hot spot of harm. Comparing Figure 7C with Figure 6C, the distribution of the sporadic hot spots of frequency and harm are largely the same. However, the dispersion of the consecutive hot spots of harm are quite different than that of frequency. The three consecutive hot spots of harm near the coast of Aceh, Indonesia are not consecutive hot spots of frequency. The only overlapping hot spot of frequency and harm is located near the coast of north Sumatra.

<Insert Figure 7C>

In the local outlier analysis of the same 144 locations, the G_i^* and S estimation procedures found 5 locations that comprise of only high-high (HH) cluster, 24 locations that comprise of only low-high (LH) outlier, 2 locations that comprise of only low-low

(LL) cluster, 22 locations that only comprise of high-low outlier (HL), and 10 locations that comprise of multiple types. Visual inspection of Figure 7D and 6D shows there are three overlapping HH only clusters, which are located along the Singapore Strait and the South China Sea. In Figure 7D, the remaining two HH only clusters are situated in the international water off the coast of Terengganu and Sarawak of Malaysia. Interestingly, the LL only cluster in the frequency analysis situated off the coast of Sarawak turns out to be a HH only cluster in the harm analysis.

<Insert Figure 7D>

In conclusion, these results corroborated with the findings of Weinborn et al. (2017) which found that the hot spots are not always the same as the harm spots. As summarized in Table 5 in the entire world there are 19 consecutive hot spots and 5 diminishing hot spots while there are 14 consecutive harm spots and 17 sporadic harm spots. For East Africa, there are 3 new hot spots, while there are 2 new harm spots and 2 sporadic harm spots. For Malacca Strait and South China Sea, there are 32 sporadic hot spots while there are 34 sporadic harm spots.

<Insert Table 5>

The results summarized in Table 6 and 7 reinforce the notion that hot spots need not be the same as harm spots. As shown, there is statistically significant evidence to indicate that the HH cluster, LH outlier, LL cluster and HL outlier for the whole world, East Africa and Malacca Strait and South China Sea are always different between the frequency and harm analyses.

<Insert Table 6>

<Insert Table 7>

*4.5 Results for Concentration of Frequency and Harm at the 3*3 Grid Level for Piracy Attacks Worldwide*

Drawing upon the hot spots of crime literature that aggregated the frequency of crime at the street segment-, police beat- or census tract-level described in Chapter 2, I rely on the 3° by 3° fishnet grid as the unit of analysis[xxvi] to illustrate the global frequency distribution of pirate attacks. Among the 7,200 the 3° by 3° fishnet grids, there are 241 grids with at least one attack. For the remaining analysis, I focus on these 241 grids and prune away grids with no attack. Visual inspection of Figure 8A confirms the existence of the four piracy hotspots denoted as grids with 72 – 170 attacks (Indian Ocean and Gulf and Guinea) or 171 – 283 attacks (Gulf of Aden, Malacca Strait and South China Sea). I find that 5 grids are responsible for 30.59 percent of all attacks, while 16 grids, or around 6.64 percent of all grids, are responsible for 49.70 percent of all attacks.

<Insert Figure 8A>

<Insert Figure 8B>

Using the same methodology, the harm spots of pirate attacks are shown in Figure 8B. Compared to Figure 8A, the grids with the highest harm during the same study period are located in the Malacca Strait and South China Sea, as well as the Gulf of Guinea (388,639 – 881,731 CHI prison days). On the other hand, the harm in the frequency hotspots of the Indian Ocean and the Gulf of Aden are relatively milder (124,892 – 232,017 CHI prison days in Indian Ocean and 232,017 – 388,639 CHI prison days in the Gulf of Aden). Here, I find that 6 grids are responsible for 30.64 percent of all harm, while 16 grids are responsible for 49.74 percent of all harm.

<Insert Figure 8C>

In Figure 8C, I compare and contrast the findings in Figures 8A and 8B by superimposing piracy hot spots for 50 percent of all attacks and harm spots for 50 percent of total harm in the same map. The color blue denotes activity nodes while red denotes harm nodes. As shown, just 16 grids, or 16/241=6.63 percent, of all grids, account for half of all activity nodes as well as half of harm nodes. Of these, there are 11 grids in which activity nodes and harm nodes overlapped – 4 in the Malacca Strait and South China Sea, 1 in the Indian Ocean, 2 in the Gulf of Aden and 4 in the Gulf of Guinea.

The 3D visualization of hot spots and harms spots and their co-locations is depicted in Figure 8D-1. This approach stands apart from the majority of crime hot/harm spot mapping techniques (or geographic maps more broadly) that commonly rely on 2D maps to show the intensity and clustering. I use ArcGlobe and ArcScene 10.5 which is normally used in software architectural analysis method to perform the 3D visualization of the concentration of statistically significant hot spots and harm spots of piracy attacks worldwide.

In the series of 3D maps shown in 8D-1 to 8D-7, the blue "volcano" denotes the intensity or magnitude of clustering of statistically significant hot spots while the red bar denotes the intensity or magnitude of clustering of statistically significant harm spots. In order to present the results in a more coherent way, I rescale the heights of the volcanos and bars to make them comparable. This is necessary because the unit of measurement for the height of the volcano (measured as the count of piracy attacks) is not consistent with that for the height of the bar (measured as the number of CHI prison days). The original harm spot bars would require more than a page to present in its entirety. To overcome this limitation, I use the height of the tallest volcano in the Malacca Strait and South China Sea to calibrate the height of all bars. After the calibration, the heterogeneity in terms of the concentration of hot and harm spots worldwide are illustrated much more prominently.

<Insert Figures 8D-1 to 8D-7>

The results obtained under this novel approach corroborate with those found earlier – 1) the most intense statistically significant hot spots are not necessarily the most intense statistically significant harm spots; 2) in Malacca Strait and South China Sea, the intensity of clustering of statistically significant hot and harm spots is greater than any other region; 3) in the Gulf of Aden and East Indian Ocean, the intensity of clustering of statistically significant hot spot is greater than that of harm spot; 4) in the Gulf of Guinea, East Africa, Central and South America, intensity of clustering of statistically significant hot spot is smaller than that of harm spot.

In Figure 9, I categorize the grids into three types – priority grids, hot spots and harm spots. I define high crime grids to be those that are responsible for the top 50 percent of all attacks and high harm grids to be those that are responsible for the top 50 percent of total harm. As Figure 8C shows, there are 11 Type 1 – Priority Grids, or 4.56 percent, which are responsible for 41.47 percent of all attacks and 40.29 percent of total harm. For Type 2 high-crime-low-harm grids which are parallel to the commonly name crime hot spots adopted in prior research, 5 grids or 2.07 percent, are responsible for 8.23 percent of attack and 5.07 percent of harm. Finally for Type 3 low-crime-high-harm grids which are commonly known as hot spots of harm, 5 grids or 2.07 percent, are responsible for 4.84 percent of attack and 9.48 percent of harm. The policy significance of the three types of grids will be discussed in the final chapter.

<Insert Figure 9>

Figures 10 to 12 explore whether there is a small number of high harm grids which are consistently harmful throughout the study period. Figure 10 plots the cumulative frequency of attacks and cumulative harm against the proportion of grids on the same figure. It shows that both frequency and harm are highly concentrated within a power few grids for the nine years combined. The cumulative attack is more concentrated than cumulative harm for the first seven percent of grids, and cumulative harm is slightly more concentrated than cumulative attack for the remaining 93 percent. The two curves overlap at seven percent of grids, meaning that seven percent of all grids are responsible for half of all attacks and harm. Half of all grids accounted for 93 and 95 percent of the cumulative frequency and cumulative harm, respectively. The exponentially shaped curves for the cumulative number of attacks and cumulative harm increase our confidence regarding the spatial clustering of frequency and harm found earlier.

<Insert Figure 10>

Figure 11 shows the breakdown for grid identified harm for each of the years included in the study. For 80 percent of harm, it increased from 4.15 percent of total grids in 2006 to 17.42 percent in 2010, before declining to 6.64 percent of total grids in 2014. One possible explanation is that high volume-low harm pirate attacks rose substantially from 2006 to 2010 and then fell sharply from 2010 onwards. The annual percentage of grids responsible for 20 percent of total harm remained relative stable (around 1 percent) throughout the study period.

<Insert Figure 11>

Figure 12 illustrates the average CHI value for the categories of power grids with few cases. The blue line shows that from 2006 to 2014, the mean CHI value for those low volume-high harm grids surged from 16,030 CHI prison days in 2006, to 83,818 CHI prison days in 2012 to 227,733 prison days in 2014, representing a 13.2 times increase. In contrast, the trend of the mean CHI value for those high volume-low harm grids denoted by the green line increased approximately three times from 11,412 CHI prison days in 2006 to 33,539 CHI prison days during the study period.

<Insert Figure 12>

Summing up this section, I tackle research question R1 with an inductive approach by attempting to find out from a large geodatabase of pirate attacks whether there is any statistically significant patterns of spatial, as well as spatial-temporal, concentration of crime and harm. As illustrated, there is strong evidence indicating that piracy attacks cluster in different parts of the world across time. When the attacks are aggregated at the grid level, similar conclusions remain valid. The theoretical and methodological value-addedness of my contributions will be evaluated in the next chapter. Policy recommendations for the police to more accurately calibrate their limited resources will also be provided.

R2) How do offender motivation, target suitability and the absence of capable guardians and their convergence impact the instantaneous risk of piracy in South East Asia?

In this section, I first present graphical evidence of the variations in trends of pirate attacks across different regions. Next, I explain the statistical interpretation of the results related to Hypotheses 1 – 4, before showing the results for the test of the proportional hazard assumptions. As explained earlier, the results for the multiple robustness checks are not included in the main text because they essentially provide the same conclusion compared to the main estimation strategy, the series hazard model.

4.6 Temporal Distribution of Pirate Attacks in Malacca Strait and South China Sea

In terms of worldwide total, the percentage of attacks perpetuated in Malacca Strait and South China Sea decline steadily from 38 percent in 2003 to 18 percent in 2008 and 10 percent in 2009. Figures 14 and 15 show two time series illustrating the variations across time in piracy attacks in the Malacca Strait and South China Sea, respectively, from 1995 to 2010. Combining the two regions, Southeast Asia as a whole experience a peak in the number of attacks from 2000 to 2004 and a trough from 2007 to 2010. The drop has been especially marked in the Malacca Strait, as demonstrated in Figure 2. Between 1998 and 2000, the number of attacks increase exponentially from 5 to 118 attacks, before it decline to 32 attacks in 2002. There is a slight increase from 32 to 60 attacks between 2002 and 2004, before the series decays to zero attack in 2009 and 2010. Turning to South China Sea, Figure 3 shows the trend in the number of attacks. For the years 1995, 1997, 1998, and 2006 to 2009, the number of attacks is below the median of 68 cases. The region is relatively 'calm' during 2006 to 2009, with an average of only around 69 cases. On the opposite end, the region is the most infested with piracy during the period 1999 to 2004, with an average almost twice that of the 'safest' period. The peak occur in the year 2000 with 145 attacks recorded during the year. Visual inspection shows that the variations across time of the attacks in South China Sea mimicked that of the Malacca Strait, albeit on a larger amplitude. I find that there is a significant correlation between yearly piracy attacks (*r=0.664, p=0.007*) in Malacca Strait and South China Sea

As displayed in Figure 13, the trend of piracy attacks in the Malacca Strait is driven mainly by attacks that are perpetuated in international waters throughout the sampling period. During the study period, the number of ships transiting the region shows an increasing trend. According to the ship traffic data compiled by the Marine Department Peninsular Malaysia (Marine Department Malaysia, 2017), in the year 2000 the number of ships passing through the region is estimated to be around 55,953. This figure increased by around 12 percent to 62,621 in 2005 and further by 32 percent to 74,133 in 2010. To determine whether the trend of pirate attacks in Malacca Strait is driven by the number of ships transiting the region each year, I computed the Pearson's correlation test. The result (*r=-0.8533, p=0.000*) indicates a strong negative correlation between pirate attacks and traffic in the Malacca Strait. The conclusion drawn from this preliminary analysis implies that increase in traffic volume does not attract more pirates to perpetuate attacks.

<Insert Figure 13>

In South China Sea, as displayed in Figure 14, the main driver of the overall trend from 1995 to 2001 is attacks perpetuated in territorial water whereas from 2002 to 2006, port piracy accounted for the majority of the cases. However, the South China Sea encompasses a very large geographical area and the number of ships passing through it cannot be easily counted, unlike the Malacca Strait. One of the possible ways to do so is to rely on Automatic Identification System (AIS) data for ships which record the arrival and departure times at the ports of destination and arrival. Due to practical constraint in obtaining the AIS data, they are unavailable and the Pearson's correlation test of the association between pirate attacks and traffic in the South China Sea is beyond the scope of my dissertation.

<Insert Figure 14>

Taken together, there is significant variations across time and space for piracy attacks that occurred in these two regions. The next section presents the results for testing Hypothesis 1-3 for each region as a whole, as well as for territorial water, international water and port.

4.7 Results for Hypothesis 1-3

Table 8 and 9 show the results of Equation (1) for Malacca Strait and South China Sea respectively for all attacks, attacks perpetuated in territorial water, international water and at port. Overall, the results provide adequate support for the three core tenets of the routine activities perspective.

In Hypothesis 1, I predict that the hazard of piracy attacks will increase in times of economic need. In support, the results indicate that for piracy attacks perpetuated during Ramadan, the hazard of piracy increases by about 36.5 percent for all attacks and by 248.3 percent for attacks perpetuated in port area. For every one-unit increase in the regional Misery Index, the hazard of piracy increases by 18.9 percent in port area only but not significantly in other areas. However, I did not find evidence in support of Hypothesis 1 in South China Sea, and in fact found that the hazard of piracy decreases in all areas and international water by 2.4 percent and 7.1 percent for every one-unit increase in the regional Misery Index.

Hypothesis 2 predicts that the hazard of piracy will increase when capable guardians are absent. Consistent with H2, in Table 8 it is shown that during the period when MALSINDO is not in operation in the Malacca Strait, the hazard of ships being attacks increases by 255.1 percent and the increase is equally potent in international water, where ships face 252.2 percent higher hazard of being attacked. For every one-unit decrease in the regional military expenditure, the hazard of piracy increases by 252 percent, 273.6 percent and 344.9 percent for all areas, territorial water and international water, respectively. Second, there is also significant evidence in support of Hypothesis 2 in South China Sea. As illustrated in Table 9, ships face a 56.3 percent 88.6 percent and 139.9 percent higher hazard of being attacked in the entire region, territorial water and international water, respectively, when MALSINDO is not in operation. Also, ships have a 16.1 percent higher hazard of being attacked when CARAT is not in operation for all attacks and the increase is most prominent in international water, where ships experience a 43.8 percent increase in the hazard of being attacked. In the same area, every one-unit decrease in the regional military expenditure is associated with a 322.2 percent increase in the hazard of being attacked. Hypothesis 2 is thus supported across both regions.

<Insert Table 8>

My next set of hypotheses relates to the attractiveness of targets. In Hypothesis 3 I predict that the hazard of piracy will increase when the value of trade passing through the region is high. Table 8 exhibits strong evidence in support of H3. It is estimated that for every unit increase in the regional trade in Malacca Strait, the hazard of piracy increases by 154.7 percent for all attacks. There is also statistically significant evidence in Table 9 in support of Hypothesis 3. For every unit increase in the regional trade in the entire

South China Sea, territorial water and international water only, the hazard of piracy increases by 37 percent, 48.7 percent and 115.3 percent, respectively.

Several of the context variables are also significantly related to the hazard of piracy attacks. For the variable "Success Density", when the three most recent pirate attacks are successful, the hazard of a new piracy attack will increase by 1.2 percent, 2.1 percent, 1.1 percent and 1.9 percent in the entire region, territorial water, international water and port area in the Malacca Strait. I notice similar contagion effects in the South China Sea but the magnitudes are slightly smaller. Specifically, when the three most recent pirate attacks are successful, the hazard of a new piracy attack increases by 0.8 percent, 0.8 percent, 0.7 percent and 0.9 percent in the entire region, territorial water, international water and port area. Next, for the variable "Last Reported", I find that when the last incident was reported to the coastal state, the hazard of the current piracy attack is 46 percent higher in the international water in the Malacca Strait, contrary to the earlier prediction. Reporting of the last attack does not affect the hazard of the current attack in the South China Sea, though.

<Insert Table 9>

<u>*4.8 Results for Hypothesis 4*</u>

The first row in Table 10 shows the estimated coefficient β_5 in Equation (2) for Malacca Strait and South China Sea. In Hypothesis 4, I predict that the hazard of piracy will increase when measures of absence of capable guardian converge with the measures of motivated pirates and suitable targets. Consistent with the prediction, the estimated hazard ratio for the three-way convergent term is positive and highly statistically significant. When the three "essential ingredients" of crime – high criminal motivation, absence of capable guardian and suitable target converge in space and time, the hazard of ships being attacked in the Malacca Strait and South China Sea increases by 74.9 percent and 23.4 percent, respectively.

<Insert Table 10>

4.9 Results for Testing the Proportional Hazard Assumptions

The scaled Schonfeld residuals for four significant predictors in Malacca Strait and South China Sea are plotted in Figure 15 and 16, respectively[xxvii]. To help visualize any systematic patterns in the residual plots, a nonparametric lowess smoother (dash line) has been added in each panel along with the zero line (solid line). Visual inspection of Figures 15 clearly shows that residuals for the covariates “MALSINDO”, “regional military expenditure” and “regional trade” scatter about zero with no noticeable departures from uniformity in the Malacca Strait. On the other hand, the PH assumption for the covariate “During Ramadan” is violated because the distribution of its residuals does not appear to conform to uniformity. For the South China Sea, visual inspection of Figure 16 suggests that the scattering of residuals for the covariates “Misery Index”, “MALSINDO” and “Regional Trade” is close to the zero line, except for the covariate “CARAT”. I conclude that the PH assumptions are not violated for three of these four variables. The residual scatter plots for the convergence terms in the Malacca Strait and South China Sea are illustrated in Figure 17. Visual inspection suggests no evidence that the PH assumption is violated because the residuals scatter smoothly around the horizontal line at 0 for the covariate capturing the convergence effect.

<Insert Figure 15>

<Insert Figure 16>

<Insert Figure 17>

<u>*4.10 Results for Alternative Survival Functions*</u>

The results from the log-normal survival model are displayed in Table 11, and the reported estimates are the coefficients of the accelerated failure time model. In the Malacca Strait, having the convergence effect term taking the value of one accelerates the time to event by a factor of exp(-0.597)=0.550, meaning the survival time compared to the baseline survival is 0.550 times shorter. Put differently, when the three-way interaction term takes value of one, the predicted survival time decreases by approximately 100x[1-exp(-0.597)]=45 percent. In passing, I note that the coefficients for the exponential, Weibull and log-logistic models which are shown to be slightly inferior to the log-normal model according to the AIC and BIC parameters are highly statistically significant and in the same direction as the log-normal model.

<Insert Table 11>

Similarly, in South China Sea, when the convergence term takes the value of one, the time to event is accelerated by a factor of 0.814, meaning that the survival time compared to the baseline survival is 0.814 times shorter. In other words, the predicted survival time decreases by 18.62 percent when the convergence effect term takes the value of one. In passing, I note that the coefficients for the exponential, Weibull and log-logistic models which are shown to be slightly inferior to the log-normal model according to the AIC and BIC parameters are highly statistically significant and in the same direction as the log-normal model.

Of fundamental interest is whether the results going from the proportional hazard model to the accelerated failure time models remain robust. Comparing with the hazard ratio for the convergence term reported in Table 10, the accelerated failure time model results in Table 11 and 12 corroborate with the semi-parametric Cox model's conclusion: The convergence of the three "essential ingredients" of routine activity theory - criminal motivation, absence of capable guardian and suitable targets – shortens the survival time compared to the baseline survival and accelerates the time to the next piracy attack. Also, the conclusions for the three hypotheses – motivation, absence of capable guardian and suitable target – remained largely the same across Table 10 and 11. In Malacca Strait, the variable "Regional Misery Index" under motivation gains significant across Table 10 and 11. Under absence of capable guardian, the variables "Regional Military Expenditure" remains significant but the variable "MALSINDO" is no longer significant in Table 11. For suitable target, the variable "Regional Trade" gains significance from Table 10 to Table 11. In South China Sea, the covariates "Regional Misery Index" "MALSINDO" and "CARAT" remains significant going from Table 10 to Table 12; while "Regional Military Expenditure" gains significance and "Regional Trade" losses significance. Taken together, the results still provide consistent support for the four hypotheses.

<Insert Table 12>

<u>*4.11 Results for Bayesian Analysis*</u>

Table 13 and 14 show the probability that the hazard of piracy attack increases or decreases when there are 1) Motivated offenders; 2) Absence of capable guardian; 3) Suitable targets in the Malacca Strait and South China Sea. Again, the results provide consistent support for the three core tenets of the routine activity perspective. Because the conclusions are the same compared with the main estimation strategy model, the results for the Bayesian analysis are presented in Appendix 3.

<Insert Table 13>

< Insert Table 14>

< Insert Appendix 3>

Summing up this section, I tap on the series hazard model as the main estimation strategy to test four hypotheses related to the routine activities perspective. I consider the results to possess a high degree of internal validity because they remain valid through multiple robustness checks.

R3) To what extend do economic conditions of fishermen impact the instantaneous risk of piracy in South East Asia and East Africa?

In this section I lay out the results for the third research question R3. After ensuring that the identifying assumptions are met, I proceed to provide the statistical interpretation for the structural equation models for hazard functions. Finally, I rerun the analysis using an alternative survival model to ensure robustness. The results are not presented in the main text because they support the prior analysis.

4.12 Results for Identifying Assumptions

The outputs of the relationship between the instrument (SST) and the endogenous variable (fish capture production) in East Africa and Malacca Strait and South China Sea combined are depicted in Table 16. According to the estimates of the mean-centered first stage OLS regression, the coefficients $\alpha_{SST} \neq 0$ and they are highly significant at the 0.1 percent level across both regions in Models 1 and 2. In Model 1, I regress fish output production on SST without the set of independent variables and controls. For East Africa, I estimate that for every unit increase in SST fish output production declines by 0.157

units. On the other hand, in Malacca Strait and South China Sea combined every unit increase in SST is associated with an increase of fish output production by 1.25 units. For East Africa, there is convincing evidence to support the conclusion that the instrumental variable X_{SST} is *inversely* associated with X_{Fish} conditional on the remaining terms in equation (26). Unlike in East Africa where SST and fish output production are inversely related, SST and fish output production are *positively* related in Malacca Strait and South China Sea combined. Specifically, for every one unit increase in the standard deviation of the sea surface temperature, the fish capture production decreases by 0.157 million tons in East Africa and increases by 1.25 million tons in Malacca Strait and South China Sea combined. For Model 2, I regress fish output production on SST taking into consideration the set of independent variables and controls. The output in the last two columns in Table 16 indicates that for every one unit increase in the standard deviation of the sea surface temperature, the fish capture production decreases by 0.165 million tons in East Africa and increases by 11.27 million tons in Malacca Strait and South China Sea combined, certeris paribus.

<Insert Table 16>

4.13 Results for Structural Equation Models for Hazard Functions

The fitted results for the first-stage as denoted by Equation (25) are shown in Table 17. Model 1 is performed without simulations in resampling whereas in Model 2, the number of simulations in resampling is set to 1,000,000. In the semiparametric additive hazards models of East Africa and Malacca Strait and South China Sea combined without simulations in resampling, the independent variable fish capture production and hazard of piracy are inversely related, which means that the hazard of piracy increases when fish output production drops. Columns 1 and 2 of Table 17 show that a one-unit increase in fish capture production is associated with a decrease hazard of 0.0609 and 0.00158 in East Africa and Malacca Strait and South China Sea combined, respectively. In other words, for every one million tons increase in fish capture production, on average the duration between attacks decrease by 6.09 percent and 0.158 percent in East Africa and Malacca Strait and South China Sea combined, respectively. Similarly, in Model 2, the semiparametric additive hazards models show that fish and hazard of piracy are inversely related. The change in hazard estimated from one million simulations in resampling indicates that for every one million tons increase in fish capture production, on average the duration between attacks decrease by 6.14 percent and 0.177 percent in East Africa and Malacca Strait and South China Sea combined, respectively.

<Insert Table 17>

As shown in Equation (25), the variable fish capture production is endogenous and its estimated coefficient will be inconsistent. To remedy the issue of endogeneity, I next quantify the effect of variation in SST on the instantaneous risk of piracy in terms of fish capture production by instrumenting the endogenous variable fish capture production with the SST measure. Under A1-3 discussed earlier, the exclusion restriction criteria is satisfied. Table 18 presents the change in hazard for the two-stage additive hazards models. For East Africa, the instrument SST is inversely related to hazard of piracy. This means that the hazard of piracy *decreases* when any decrease in SST leads to an increase in fish output production. On the other hand, for the Malacca Strait and South China Sea combined, the instrument SST is inversely related to the hazard of piracy. This means that the hazard of piracy *increases* when any decrease in SST leads to a decrease in fish output production.

<Insert Table 18>

Comparing the point estimate of East Africa (column 2) in Table 17 with that in Table 18, the magnitude of the estimates are quite similar. I find that there is statistically significant evidence at the 99 percent confidence interval to indicate that the protective effect of fish capture production on the instantaneous risk of piracy remains robust, and in fact decreases by a non-trivial order of magnitude (around 0.07 percentage point or 1.1 percent) for the first column. Specifically, the coefficient estimate depicted in column 1 of Table 18 implies that a SST decrease that leads to an increases of fish catch production by 1 million tons *decreases* the hazard by approximately 6.16 percent.

Comparing the magnitude of the point estimate of Malacca Strait and South China Sea combined (column 3) in Table 17 with that in Table 18, the results are quite striking. I find that there is statistically significant evidence at the 99 percent confidence interval to indicate that the protective effect of fish capture production on the instantaneous risk of piracy remains unchanged, and in fact decreases by a non-trivial order of magnitude (around 0.01832 percentage point or 11.59 times) for column 3. Specifically, the coefficient estimate depicted in column 3 of Table 18 implies that a SST decrease that leads to a decrease in fish catch production by 1 million tons is associated with an *increase* of the hazard by approximately 1.99 percent.

Compared to the point estimate of Malacca Strait and South China Sea combined of Table 17, with that presented in Table 18 indicates the presence of an upward bias in the case of the semiparametric additive hazards model. Very clearly, removing the inherent endogeneity associated with the fish capture production variable by instrumenting with SST yields absolute effect size substantially much larger, and the level of significance also improves from $p \leq 0.05$ to $p \leq 0.01$.

Model 2 in Table 18 tells a similar story. Based on 10,000 simulations in resampling, the change in hazard increased from -6.16 percent in Model 1 to -6.04 percent in Model 2 for East Africa, and decreases from -1.99 percent in Model 1 to -2.15 percent in Model 2. Comparing Model 2 in Table 17 with Model 2 in Table 18, instrumenting with SST to remove the endogeneity associated with the fish capture production results in a substantially larger absolute effect size (11.15 times).

4.14 Results for IV for Cox Proportional Hazards Model

To recap, in Hypothesis 5 I rely on the "Optimal Participation in Illegitimate Market Activities" framework to model the behavior of part-time fishermen part-time-pirates who are assumed to allocate their time between legal (fishing) and illegal (pirating) activities. According to this framework, the equilibrium proportion of time devoted to fishing is a negative function of the legitimate income from fishing activities. To ensure robustness of the findings presented in the earlier analyses, I rerun the models with the Cox proportional hazards model. As explained earlier, the results are not presented here because they do not provide a different set of conclusions compared to the main analysis. The results from the Cox models corroborate the semiparametric additive hazards model's finding - The hazard of piracy is inversely related to fish output production. This finding remains valid even after instrumenting fish output production by SST in both sets of models. The results are presented in Appendix 4.

< Insert Appendix 4>

4.15 Chapter Summary

In the first part of this chapter, I show the spatial-temporal concentration of attacks worldwide, in East Africa and Malacca Strait and South China Sea. A common theme in these analyses is that with the exception of the Malacca Strait and South China Sea, the statistically significant hot spots are not always the statistically significant harm spots. A natural question to follow is how those spots that are both frequent and harmful be identified. To identify these co-locations, I analyze the concentration of attacks and harm at the grid level using both 2D and 3D visualization techniques which are novel in Criminology. Those grids that are identified as co-locations are the power-few priority grids for targeting.

In the second part of this chapter, I find a statistically significant impact of offender motivation, target suitability and the absence of capable guardians acting individually, as well as the convergence of these terms, on the instantaneous risk of piracy attacks in the Malacca Strait and South China Sea. The findings remained robust even when I relaxed some of the parametric assumptions of the original series hazard model and adopted alternative survival functions. Perhaps more importantly, the conclusions drawn earlier remained valid even when the frequentist approach was dropped in favor of the Bayesian approach.

Finally, I verified that economic conditions of fishermen have a non-trivial impact on the instantaneous risk of ships being pirated in both South East Asia and East Africa. Both the instrumental variable for semiparametric additive hazard model and Cox proportional hazard model led to the same conclusion – hazard of piracy is inversely related to fish capture production, although the impact of global warming on fish output is in the opposite direction for both regions.

In the next chapter, I plan to present the implications of the three sets of results. For theoretical implications, I plan to lay out the contributions of my findings to the crime concentration at places literature, environmental criminology and crime pattern theory using the first set of results. Next, I plan to discuss how my findings for R2 complements as well as expand our present understanding of the routine activities perspective. Last but not least, I rely on the findings for R3 to argue how rational choice theory can be operationalized using the economics of crime framework to test the relation between economic conditions and crime. For policy implications, I plan to articulate how my findings for R1 can be used as evidence to enhance existing deployment of limited police resources and redesign of targeting strategies. Because crime/harm locations and shipping routes are already known, another strand of policy implication relates to the shipping and insurance industry. The policy relevance for the set of results related to R2 will be examined in relation to the shipping industry and coastal law enforcement agencies. For R3, I plan to contextualize the policy relevance to the current debate on climate change and political instability. Given that I consider this dissertation to be just the first step towards the scientific study of the causes of, and responses to, piracy, I outline the limitations in the areas of data quality, measurements, and appropriateness of methods. Finally, I lay out a plan for future research to address some of the interesting topics that remain unexplored in this dissertation due to practical limitations and data availability.

Chapter 5: Discussion and Conclusion

In this final chapter, I seek to discuss the substantive interpretation of my statistical findings from the previous chapter in section 5.1. In section 5.2, I elucidate the theoretical and methodological value-added of my contributions in three parts. First, my findings are discussed in relation to the crime count and harm concentrations at places. In the second and third part, I explain the ways in which my findings broadened the existing conceptualization of the routine activities perspective and rational-choice theory, respectively. In section 5.3 the policy implications based on my findings are presented. Specifically, I evaluated several recommendations to the police and policy makers based on cost-effectiveness considerations. While my findings remained valid through multiple robustness checks, it remains possible that some threats to the internal validity exist. In section 5.4, I review the potential limitations of my dissertation in three areas – conceptual, data and methodological. To confront these limitations, in section 5.5 I cover the future research plan based on these weaknesses. I discuss the ways in which theoretical and methodological underpinnings not adopted in the current research could be contextualized and explore ways to provide a larger context for my results. Last, I conclude the dissertation with some final thoughts in section 5.6.

5.1 Summary Findings

The substantive interpretation of my statistical findings from the previous chapter are provided in this section. I first discuss the significance of the spatial and spatial-temporal clustering of hot spots and harm spots for environmental criminology for R1. Next, I explain the four hypotheses related to the routine activities perspective and the meaning of their statistical significance in the context of piracy for R2. Last, for R3 I focus on explaining the results of the proximate situation which leads to the exploration of how the rational pirate-fishermen make the decision to break the law.

A huge proportion of studies in environmental criminology that examine the nexus between crime and place exclusively use crime frequency data (Weisburd, 2015). Most of the hot spots identified in prior research were computed using two-dimensional spatial information only. With the exception of the series of trajectory studies performed by Weisburd and colleagues in 2004 and 2009 which aimed to test whether the patterns of crime concentrations for groups persisted over time, there is a paucity of evidence indicating whether each unique spatial hot spot exhibits any spatiotemporal pattern of clustering when the third dimension (e.g. time) enters the model Although Townsley (2018) outlined the framework of applying situational theories to study maritime piracy, he did not perform any empirical testing of these perspectives. Building upon his conceptualization, in the first research question R1 I endeavor to fill the void in our understanding of environmental criminology, crime pattern theory and crime concentration at places when these situational theories are tested in the context of maritime piracy. Examining the spatial-temporal concentrations of pirate attacks worldwide, I find significant evidence of clustering of hot spots in the Malacca Strait and South China Sea, and significant evidence of clustering of cold spots in the Gulf of Aden and the West Indian Ocean. Examining Malacca Strait and South China Sea alone, the optimized hot spot analysis that takes into account spatial information only indicates that the significant hot spots are clustered along the Malacca Strait to the northwest of Singapore. When considering both spatial and temporal dimensions in the local outlier analysis, the evidence shows that the high-high clusters are located to the northeast of

Singapore. Similarly, for the Gulf of Aden and East Africa, I find that when the temporal dimension is simultaneously entered into the model, the statistically significant hot spots clustering along the Gulf of Aden and the statistically significant concentration of cold spots along the West Indian Ocean lose significance. Instead, the emerging hot spot analysis and the local outlier analysis indicates that there is statistically significant evidence of clustering of consecutive hot spots and high-high clusters along the Gujarat, Mangaluru, and Kochi regions. The conclusions drawn from the space only analyses corroborate with the established body of literature which illustrates the clustering of crime counts in unique places (Sherman, 1995). Because the novel approaches adopted in the space and time analyses have seldom been performed in criminology, I could not situate the significance of my findings within the realm of the current literature even though true situational theories would entail the interaction of space and time in their explanation of crime, as Wikstrom (2014) and Wikstrom et al. (2015) argued. The policy implications for incorporating time into the decision making of how and where to allocate scarce policing resources will be elaborated later in this chapter.

With the exception of Weinborn et al. (2017), very few studies have compared and contrasted the similarities and differences between the concentration of the count of crime and harm of crime. As the authors opined, the current practice of considering count only instead of both count and harm in the computation of hot spots is crude. Moreover, even fewer studies have elucidated whether the spatial and spatial-temporal clustering of the harm of crime exhibit the same pattern. The second part of R1 expands our current state of knowledge on environmental criminology, crime pattern theory and crime concentration at places by examining whether the harm of pirate attacks exhibits any statistically significant concentration patterns. Using the Cambridge Crime Harm Index to operationalize the cumulative harm of each attack, I compared and contrasted hot spots and harm spots on a global scale, in the Malacca Strait and South China Sea and East Africa. In the first of the three analyses, I conclude that: 1) most of the statistically significant hot spots of count and statistically significant hot spots of harm coincided in the Malacca Strait and South China Sea; 2) in the East Indian Ocean most of the statistically significant hot spots of count are statistically significant cold spots of harm; 3) in the West Indian Ocean most of the statistically significant cold spots of count are statistically significant hot spots of harm; 4) in the Gulf of Aden most of the statistically insignificant hot spots of count are statistically significant cold spots of harm; and finally, 5) in the Gulf of Guinea, most of the statistically insignificant hot spots of count are statistically significant hot spots of harm. The results of the second of the three analyses comparing hot spots and harm spots in the Malacca Strait and South China Sea provide strong support for the following conclusions: 1) in the Strait of Singapore, statistically insignificant hot spots remained statistically insignificant harm spots; 2) in the Malacca Strait to the northwest of Singapore and South China Sea to the northeast of Singapore, statistically insignificant hot spots became statistically significant harm spots; 3) along the coast of Vietnam, statistically insignificant hot spots became statistically significant cold spots of harm; and 4) along the coast of Java, Indonesia, statistically insignificant hot spots became statistically significant cold spots of harm. In the last of the three analyses looking at the similarities and differences in hot spots and harm spots in East Africa, I conclude that: 1) in the Gulf of Aden, most of the statistically significant hot spots of count are statistically significant cold spots of harm; 2) in the West Indian

Ocean, most of the statistically significant cold spots of count are statistically significant cold spots of harm; and 3) in the Arabian Sea, most of the statistically significant cold spots of count are statistically insignificant hot spots of harm. Even though these conclusions are drawn in the ocean for a very unique type of crime, they are nonetheless quite comparable to the findings of Weinborn et al. (2017) which indicated that in one major city in England and Wales, there was significant evidence of unique hot spots and harm spots, as well as what the authors called co-locations (overlapping hot spots and harm spots). The resultant policy implications for targeting scarce police resources will be discussed later in the chapter.

In the emerging hot spot analysis that computes the trend of hot spots over time by using both spatial and temporal information, similar conclusions are reached in the global analysis compared to the space only analysis. Most of the consecutive hot spots of count overlapped with the consecutive hot spots of harm in the Malacca Strait and South China Sea. For East Africa, I conclude that 1) most of the statistically significant new hot spots concentrated near Gujarat, India are also statistically significant new harm spots; and 2) the statistically significant sporadic hot spots near Kochi, India are statistically insignificant sporadic harm spots. In the Malacca Strait and South China Sea, I conclude that 1) the majority of the statistically significant sporadic hot spots concentrated near the Strait of Singapore and South China Sea are also statistically significant sporadic harm spots; and 2) the three statistically insignificant consecutive hot spots in the Malacca Strait became statistically significant consecutive harm spots. These conclusions remain largely the same in the local outlier analysis. On the global scale, I find that most of the hot spots and harm spots are unique. For instance, the nine high-high clusters of count dropped to just two in the harm analysis, while the number of low-low clusters increased from 91 to 149. However, when moving to the Malacca Strait and South China Sea regional analysis, most of the high-high and high-low clusters in the count analysis are also the same type of locations in the harm analysis. In the Gulf Aden, there was statistically significant evidence for one high-high cluster of count and three high-high clusters of harm, suggesting that attacks there are both frequent and harmful.

In the second research question R2, I rely on various survival models to test four hypotheses consistent with the routine activities perspective. The core principal of the perspective rests upon the argument that for a pirate attack to take place, there must be space-time convergence for the three rudiments of the perspective. Along this line of reasoning, I argue that places with very high levels of motivated pirates, absence of capable guardians and suitable targets will be positively related to the risk of being attacked. Consistent with this rationale, I expect the hazard of piracy will increase in times of economic need; when counter-piracy joint operations are not in effect; when the regional military expenditure is low; when the value of trade passing through the region is high and when the ship type is a merchant vessel. Moreover, I expect that the convergence of the three ingredients to yield a hazard ratio that is high. As far as I am aware of, this is the first study that tested the empirical validity of the routine activity perspective outside land. The multivariate hazard models provide significant evidence for all four effects. Overall, I find that there is statistically significant evidence to suggest that measures for criminal motivations and suitable targets are associated with high hazards of ships being attacked, while those of capable guardian are associated with low hazards of ships being attacked. The convergence of the measures of motivation, suitable target and lack of capable guardian is positive and significant, suggesting that the convergence in space and time of the three ingredients of crime is associated with a high hazard of ships being attacked. As robustness checks, I first utilized the scaled Schonfeld residuals plots to assess the proportionality assumption graphically. Through the use of a nonparametric lowess smoother, I find that residuals scatter about zero with no noticeable departures from uniformity. Finally, using accelerated failure time model, I again confirm the existence of a positive and significant three-way convergence effect in Malacca Strait and South China Sea.

Piracy is a situated event that is tightly coupled to the environment where the pirates organize their daily routines. As Felson and Clarke (1998) would agree, "*opportunity makes the pirate*". The situation in which the pirate is embedded, determines the benefits and cost of various courses of action, and piracy is assumed to be increased by the benefits and reduced by the costs. Variation in this benefit-cost trade-off, generated by differences in the daily routines of fishermen who are also part-time pirates, will cause piracy rates to fluctuate. The last research question R3 focuses on the proximate situation and opportunity which leads to the exploration of how offenders make the decision to break the law. Following Fluckiger and Ludwig (2015), I frame the testing of economic conditions and crime through the rational-choice perspective structured in the context of maritime piracy. This perspective predicts that a rational pirate maximizes his expected utility based on the optimal devotion of his time to either fishing or piracy. According to this line of reasoning, I tested the hypothesis examining whether the fisherman-pirate engages in more pirate attacks when the income from fishing is low, assuming that he allocates his effort strictly between the legitimate (fishing) and illegitimate (pirating) activities. Using a novel approach which was recently introduced in the medical literature, I find that there is statistically significant evidence to support the conclusion that economic conditions of the fisherman-pirate influence the instantaneous risk of ships being attacked in East Africa and Malacca Strait and South China Sea.

In conclusion, this section summarizes the substantive interpretation of my statistical findings derived from the previous chapter for three research question which tested the environmental criminology theory, routine activities perspective and rational-choice theory. The following section provides the theoretical and methodological interpretation of my findings.

5.2 Theoretical and Methodological Implications

The theoretical and methodological interpretations of my findings are presented in this section. I first discuss the theoretical as well as methodological significance of my findings for R1 by situating the grid-level analysis results within the environmental criminology literature. For R2, my findings add value to the prior studies testing the routine activities perspective in at least two ways – convergence effect of the three ingredients and longitudinal design to account for varying levels of motivation over time. The value-addedness to the rational choice theory from my findings are discussed.

5.2.1 Theoretical Implications for R1

The proposition that a small percentage of locations experience a disproportionate volume of all crime committed has been well-documented in studies performed across various countries (Weisburd, 2008; Weisburd et al. 2012). Townsley (2018) predicted that the law of crime concentration at places would hold in the context of maritime piracy. My findings are in line with this body of literature. Compared to Weisburd et al. (2004) who found that between 4 – 5 percent of all street segments accounted for more than half of all incidents reports; Weisburd et al. (2009) who found that between 3 – 5 percent of all street segments were responsible for all juvenile offending; as well as Curman et al. (2014) who reported that 7.8 percent of the street segments accounted for 60 percent of crime; my results reveal that 6.64 percent of all grids are responsible for 49.7 percent of all attacks. In terms of harm, I find that 6.64 percent of all grids account for 49.74 percent of total harm. My results are most comparable to Weinborn et al. (2017), who found that 3.26 percent of all street segments accounted for half of all crime and 0.96 percent of all street segments were responsible for half of crime harm. With the exception of this study, I was unable to locate any other published work that examined the clustering of hot spots and harm spots across both space and time. This is surprising because public perception of the seriousness of crime has a long tradition in our field (Sellin and Wolfgang, 1964; Wolfgang et al. 1985). In terms of theoretical implications, my research is novel to the extent that it validated the external validity of the crime concentration at places perspective by testing it in the oceans. For the crime concentration at places perspective to remain valid in an era of scarce resources, it is important for future research studying criminogenic places to be based on crime harm in addition to crime events.

5.2.2 Theoretical Implications for R2

For the second research question R2, my study contributes to the routine activities perspective by relaxing the assumption that offender motivation remains static. Since

Felson and Cohen (1981), Cornish and Clarke (1986) and Cook (1986) which assumed that offender motivation is fixed, most prior studies employing the routine-activities perspectives failed to take into account the interaction between the offender and the situation which implies that motivation should instead be dynamic and varies with each characterization of the confronting situation. My findings suggest that variables measuring the motivation of the pirates are positively related to the hazard of piracy. The implication for theory is that while it is reasonable to hold motivation as fixed in a cross-sectional design, it should be allowed to vary when longitudinal data measuring different levels of motivation in a population over time are available as LaFree and Birbeck (1993) recommended. The second theoretical contribution of my dissertation concerns the convergence of the three ingredients of the routine activities perspective, which the bulk of prior studies failed to consider. I show that the decrease in the instantaneous risk of piracy when the three ingredients converge is greater than each ingredient alone, as the routine activities perspective predicted. Still, little remains known about the empirical validity of the convergence effect outside of maritime piracy. Future research which endeavor to test the theoretical proposition of Felson should verify the external validity of my findings for more ordinary crimes on land.

5.2.3 Theoretical Implications for R3

My findings contribute to the rational-choice theory by drawing upon the theoretical underpinnings of the economics of crime literature to show the impact of economic conditions on crime. Relying on the utilitarian framework, my findings extended the external generalizability of Becker (1968) by studying a unique type of offense in the ocean. Given that very limited prior studies in criminology to my knowledge have directly tested the economics of crime model of Ehrlich (1973) that focuses on the proximate situation and opportunity, my findings serve to show that criminology can indeed benefit from Ehrlich (1973) who expanded Becker (1968) by including a time-allocation component. Future studies in criminology which desire to test the rational-choice theory should consider moving beyond Becker (1968)'s original formulation of the utilitarian framework because the rational-choice theory can also be conceptualized in terms of the offender's optimal time allocation.

In summation, this section presents the theoretical and methodological interpretations of my findings for the three research questions. Next, based on my findings I make a list of recommendations which are of high practical value to the police and policy makers.

5.3 Policy Implications

The task of developing evidence-based policy measures that address maritime piracy is important but challenging. If the conclusions found in my dissertation are replicated in subsequent research using different data set and methods, they have some important policy implications. In this section, I formulate several policy recommendations for the police to better organize their scarce resources and maximize the crime and harm reduction benefits per dollar spent based on the findings for R1. For R2, I made several recommendations to the policy makers in the littoral countries in Malacca Strait and South China to complement their existing effort to fight piracy. In R3, I provide some possibilities for the Somali authorities to consider in their endeavor to fight piracy when the projected sustained increase in ocean temperature is expected to remain.

According to the results of the space only analysis, policing resources should be deployed to fight pirate hot spots to the northwest of Singapore. On the other hand, results of the space and time analysis indicate that police should concentrate their resources to the northeast of Singapore. Likewise, in East Africa, compared to the spatial-temporal analysis, the space only analysis led police to target their resources in a totally opposite direction. These findings imply that to deter piracy through their hot spots policing strategies, the police should always consider three dimensions rather than two, if such data is available.

Merely tallying the frequency of crime in a particular location across time is a cost-ineffective crime-prevention strategy, as suggested by Ratcliffe (2015) and Sherman et al. (2016). As my conclusions illustrate, both the concentration of the counts and harm should be analyzed in the ecological study of maritime piracy. The police should focus their limited resources on higher risk locations – places where not only the most crimes but also the most harmful crimes are occurring. It is important to get the public, the media, the politicians and the police to differentiate between different places based on different risk of different harm. There are three things that needed to differentiate – where the police are needed because of both the number and the seriousness of crime;

Assuming that my methods are defensible and the conclusions drawn are credible, piracy harm is no more condensed in space than piracy count. Around 6.64 percent of all grids are responsible for half of all attacks, as well as harm. Because of the vast expanse of the ocean and to conserve resources, I suggest that the police should focus most of their attention to piracy hot spots and harm spots (co-locations). The 11 “Type 1” Priority Grids which are responsible for 41.47 percent of crime and 40.29 percent of harm should be the grids that deserve targeting. Four grids are located along the Malacca Strait and South China Sea, one along the coast of Bangladesh, two in the Gulf of Aden and four in the Gulf of Guinea. 11 grids out of a total of 241 grids (4.56 percent) analyzed can be easily patrolled by the coastal police of the littoral countries or through the coordination of the United Nations. Some of the incumbent endeavors to combat piracy in these grids include MALSINDO and the Malacca Straits Patrol in the Malacca Strait, Task Force 151 in the Gulf of Aden and joint naval exercises conducted by Africom in the Gulf of Guinea.

If additional resources are available after targeting the “Type 1” Priority Grids, the secondary targets should be the “Type 2” Hot Spots and “Type 3” Harm Spots. A parallel can be drawn between the former and what has been commonly named hot spots in prior studies. Five of such grids account for 8.23 percent of crime and 5.07 percent of harm. These figures mean that pirate attacks perpetuated in these grids are high volume and low harm which can be interpreted as non-violent trivial crimes. There are three such grids in the Malacca Strait and South China Sea, one in the Gulf of Aden and one off the coast of Tanzania. For the “Type 3” Harm Spots, just five grids are responsible for 4.84 percent of attacks and 9.48 percent of harm. Most of the attacks in these five grids are low volume high harm types such as hijacking, destroying ships and endangering their safety. Once the specific types of offenses in each grid are identified, the police can implement crime reduction strategies. For instance, in the Gulf of Aden, in 2017 ships are given advice by the Combined Maritime Forces to pass through the Maritime Security Transit Corridor in groups “…between 44 00 East in the Gulf of Aden and 13 00 N in the Southern Red Sea during the hours of darkness and exit the Traffic Separation Scheme to the West of the Hanish Islands in daylight hours" so as to reduce the chances of hijacking (CMF, 2017). For the rest of the 220 grids which represent 91.29 percent of all grids with at least one attack, they account for 45.46 percent of crime and 45.16 percent of harm. These scattered low crime low harm grids present a complex task in terms of targeting by the police because there are just an overwhelming number of grids with just a few attacks each over one year. To attain the highest "bang-for-the-buck", I do not recommend the police to allocate resource to target these grids.

Based on my findings, another potent policy implication is to develop a living tool that predicts upcoming hotspots, or at least the most recently hot spots. From a methodological perspective, this approach is defensible because the parameter for each time step interval in the space time cube can be manually set to units such as weeks, or even days, to take into consideration the most recent events. Given that the pirate attacks in the IMO-GISIS database are updated on a daily basis, the coastal police can deploy their limited resources to the new hot spots or harm spots or their co-locations in the most cost-effective manner. Moreover, shipping companies can also rely on these analyses to make planning for the shipping route to minimize the probability of being victimized.

Several policy recommendations can be drawn from the findings of the second research question R2. First, I conclude that new piracy attacks are more likely to be undertaken at the port area in times of economic hardship. A ship that is moored at a dock in a port or harbor when it is not at sea is comparable to a "floating building". Thus, pirates who enter the ship unlawfully for theft engage in a crime that is no different than burglary perpetuated on land. Therefore, policy makers can draw upon the immense evidence regarding the support of routine activity theory when applied to the context of property victimization to combat port piracy. The best predictors of property victimization such as home occupancy, target hardening measures and possessing valuables or portable goods can then be applied to the context of port piracy. Just like properties, ships moored at dock can benefit from the operationalization of the defensible space concept. Another policy recommendation backed by strong evidence in R2 is that anti-piracy joint operations are highly effective against the risk of being pirated. For instance, the military intervention MALSINDO greatly increased the presence of capable guardians in the Malacca Strait as it provided the means for each coastal state to conduct individual patrols in waters under its own jurisdiction whilst allowing hot pursuits to be continued even in each other's territorial water. Another potent policy is to step up the pace of modernization plans by littoral countries in Malacca Strait and South China Sea by increasing their defense budgets. However, such efforts are often hampered by economic downturns. For example, Indonesia and Thailand were forced to cut back their defense budgets by 40 and 30 per cent in the immediate aftermath of the 1997 Asian economic crisis. The same happened to Malaysia and Philippines, which halted existing modernization plans to their naval forces. The bottom line is that the trend of piracy is not unamendable and countries with low military expenditure should step up the pace of modernizing their enforcement fleet.

The policy recommendations based on the third research question R3 are specific to each region as the impact of global warming exerts a positive influence on fish capture production in Malacca Strait and South China Sea, and a negative influence in East Africa. For the former, an increase in sea surface temperature will bring about an increase in fish capture production. The hazard of piracy attacks falls as the economic condition of the fisherman-pirate improves. However, in East Africa an increase in sea surface temperature will bring about a decrease in fish capture production and a worsening of the economic prospect of the fisherman-pirate. As a result, the hazard of piracy attacks increases. These findings imply that in contrast to East Africa, the long-term increase in the sea surface temperature brought about by climate change in Malacca Strait and South China Sea may actually act as a strong deterrent to piracy. If the long-term global warming trend continues into the foreseeable future, the war against piracy in East Africa will become increasingly daunting. The unemployment of fishermen when fish capture production is low reduces the feasible set of actions, and allocating more of their time to pirating may become the best alternative strategy according to the prediction from the economics of crime models. To the policy makers, the question then becomes how to decouple the link between legitimate (fishing) and illegitimate (pirating) activities? Can some of the monetary resources allocated to the incumbent regional and international efforts to combat piracy be redirected towards the knifing off of the connection between fish output and piracy? What are some of the feasible ways to diversity a fisherman-pirate's income profile? Income diversification means that the Somali authorities provides subsidies to low-income fishermen in times of poor catch, provide them technical training to boost their job prospects in a changing environment, or provide assistance to aspiring fishermen to start their own fish farming business. One way to materialize these plans is to redirect the income from fishing licenses granted to foreign vessels to compensate the local fishermen. Somali authorities should continue to explore what more can be done to break the inverse relationship between fish catch and risk of piracy, and how to enhance the sustainability of the sector and less dependent of the weather.

Summing up, in this section I furnished several policy recommendations to the police and policy makers based on my findings for the three research questions. In the next section, I consider conceptual, data and methodological limitations inherited in my dissertation.

5.4 Limitations

Although I rely on three core components of situational perspective to frame my study of maritime piracy, and the results held up to multiple robustness and sensitivity checks, several limitations are present. In this section, I first discuss the caveats of my conceptual models before explaining some of the inherited weaknesses of the IMO-GISIS database. Next, I evaluate the shortcoming of my methodological approach when important environmental variables are absent.

5.4.1 Conceptual Limitations

As LaFree and Birbeck opined in 1991, a situation links the behavior of an individual "as a response to the changes in the environment" (p. 75). Therefore, testing a true situational theory of maritime piracy requires the conceptualization of the key rudiments in Crime Prevention Through Environmental Design or CPTED such as the management of defensible space, territoriality and target hardening in the context of this specific type of crime. Due to limited data, the variables operationalizing these concepts have not been incorporated into my dissertation.

Townsley et al. (2015) explained that the maritime industry embraced the importance of the CPTED perspective through its adoption and promotion of the Best Management Practices or BMP, a set of recommendation for ships passing through known dangerous zones. The industry group of the IMO published the BMP, which is a list of private counter-piracy measures loosely based on the twenty-five techniques of situational prevention of Cornish and Clarke (2003) and Eck and Clarke (2003). The BMP claimed that these measures were derived from "experience and data collected by naval forces…and the application of the recommendations can and will make a significant difference in preventing a ship becoming a victim of piracy" (Operations, 2011:1). According to the theoretical model of Cornish and Clarke (2003:90), the twenty-five techniques could be grouped under five main pillars, which are "1) increase the effort; 2) increase the risk; 3) reduce the rewards; 4) reduce provocations and 5) remove excuses". In the context of piracy, specific measures within the BMP that fall under the first pillar - increase the effort -include passive safety recommendations such as physical barriers including barbed wire, water spray and releasing slippery substances on the hull to make climbing difficult; enhanced bridge protection using fabricated metal or blast resistant film to prevent pirates from taking control; control of access to bridge, accommodation and machinery spaces; safe muster points for the crew to await rescue and to identify those on deck as pirates; and recordings of barking dogs[xxviii]. Active safety recommendations within the BMP include maneuvering practice such as driving a zigzag course at high speed, unarmed and armed private security guards. However, resistance by armed security guards is only possible if the cargo is inflammable. Some specific measures that fall under the second pillar - increase the risk - listed in the BMP include watch keeping and enhance vigilance through the provision of additional lookouts, using night vision optics and maintaining radar watch; high-pitch alarms that demonstrate to the pirate that the crew is aware and reacting to the imminent attack; and upper deck bright lights to show to the pirates that they have been observed; the use of closed circuit television to monitor vulnerable areas. Last, ship owners and captains play a vital role in reducing provocations. They could decide whether to take their chances by transiting the high risk areas at the right speed and at the right time when naval protection is offered.

As mentioned earlier, these salient features of situational crime prevention related to maritime piracy have not been incorporated into the present study due to lack of appropriate measures. Although there is ample evidence that techniques of target hardening within situational crime prevention reduce crime, its empirical testing in the context of piracy is nonexistent to the best of my knowledge. Therefore, it is imperative that future research attempting to test the situational perspective of maritime piracy build these theoretical constructs into the model from the ground up. One specific dimension of the CPTED perspective related to unarmed and armed private security guards, and one data source where ship-level information is available, will be discussed later in the chapter

Another relevant theory which is beyond the scope of this endeavor is the Situational Action Theory (Wikstrom, 2014). It links situational aspects with social aspects in an attempt "…to overcome the fragmentation and poor integration of key criminological insights about the role and interplay of relevant personal propensities and environmental inducements in crime causation and its dependence on the wider social context" (Wikstrom and Trieber, 2016: p.428). Due to the challenges in operationalizing key constructs using my dataset, such as the neuroscientific basis of the pirates, I provide only a partial test in the current endeavor. The empirical testing of the fully-fledged version of the SAT is reserved for future research.

5.4.2 Data Limitation

In the grid-level analysis of R1, the numerator, or the frequency of attacks is known but the denominator, or the total number of ships passing through each grid, remains unknown. The distribution of the count of pirate attacks is not truly comparable across girds unless we can compute the *rate* of attack per say 100,000 ships transiting each grid. Without knowing the number of ships transiting each grid, the comparison of counts across grids is biased because the count of attacks in some grids can be heavily influenced by the sheer volume of traffic passing through.

Despite the positive findings, some caveats regarding the IMO data quality should be taken into consideration when interpreting the results. While I do not disagree with the view that the IMO-GISIS data possesses many desirable characteristics for conducting cross-regional comparisons of maritime piracy risks, two problematic issues should be noted – self-selection in reporting and under reporting. First, successful attacks may be more likely to be reported because ship owners must make official reports to substantiate an insurance claim. For the problem of under reporting, merchant ship owners have little incentive to file an official report because the time needed for the investigation process is long and expensive demurrage will be incurred. The incentive to report an attack is diminished when a mark of being attacked substantially increases the future insurance premium. However, it is worth noting that this is a general problem with most property crimes and not specific to maritime piracy.

When the brand of the carrier is tarnished, customers may also lose confidence and no longer perceive the carrier to be safe and reliable. While these scenarios suggest that undercounting of piracy attacks is a significant problem even in international organization such as the IMO and IMB with highly developed statistical capacity, the true magnitude of the measurement error is seldom known. Despite the weakness, I argue that the estimates are conservative and represent the lower limit for the actual number of attacks. Improved quality and quantity of piracy attack data are needed in every country, particularly in piracy hotspots such as the Malacca Strait and South China Sea. Policy makers in every country located along these regions should heighten the official endeavors directed to the increase coverage and systematic recording of all attacks, in addition to self-reporting by the victim vessels.

5.4.3 Methodological Limitations

Several methodological limitation exist in my analyses. First, I dichotomized the variables that were used to construct the convergence term using the median. It should be noted that the dichotomization of continuous variables is known to possess some serious drawbacks. Research suggests that there is no good reason in general to suppose that there is an underlying dichotomy, and if one exists there is no reason why it should be at the median (MacCallum et al., 2002). Dichotomizing leads to several other problems. First, the statistical power to detect a relation between the continuous variables and the survival duration is reduced as much information is lost. The authors have shown that dichotomizing a variable at the median reduces power by the same amount as would discarding a third of the data. Since this test is probably conservative, the estimates may represent a lower bound, suggesting that the true effect may be larger.

Second, although my analysis included a variety of controls to rule out the possibility of confounding the dependent variable, it does not address the environmental factors which influence the risk of piracy. As highlighted in the section Conceptual Limitation, anecdotal evidence suggests that various aspects of the physical environment such as maximum height of the wave, monsoon seasons and the availability of moonlight affect the risk of piracy (Pflanz, 2009). According to Shortland and Vothknecht (2011), the logic is that during monsoons, "strong winds coupled with high waves of a short wavelength, can be dangerous for the pirate skiffs" (p.141). They used the IMB database to test these hypotheses informed by this aspect of the CPTED approach in the Gulf of Aden. The logistic regression results showed that the odds of attacks are around 10 to 15 percent lower during monsoon season, and around 6 percent higher during full moon nights. Also, Cook and Garrett (2013) posited a similar set of hypotheses and relied on satellite observations to approximate marine weather data in the Western Indian Ocean. They found that when the speed of wind exceeds 9 meters per second or when the maximum wave height exceeds 2.5 meters, the incidence of piracy drops a great deal and no successful attacks occurred because the strong winds and waves may capsize the pirate skiffs. However, the internal validity of the finding is weak. The authors warned that the satellite observations provide just an "alternative for oceanographic data east of Somalia" (p.310) because the most appropriate marine weather data captured by buoys and floats are not available in the Western Indian Ocean due to the risk posed by pirate attacks (Smith et al. 2011). Due to practical constraint, limited data and weak statistical power, it is beyond the scope of my dissertation to control every factor that has been identified in previous research to study the concentration of attacks risk of being victimized. The studies reviewed here provide us with a starting point for future research aiming to examine the concentration of attacks and harm and their overlap. Depending on data availability and sample size, variables such as maximum height of the wave, monsoon seasons and the availability of moonlight shipping routes, state status and chokepoints should be controlled for, should become part of the control variables in future research.

In conclusion, in this section I openly acknowledged some of the shortcomings of my conceptualization of the research problem, dataset employed and methodological approaches.

To confront these limitations, I lay out a plan for future research in the hope of addressing some of these issues.

5.5 Future Research Plan

To overcome the data limitation highlighted earlier, in this section I argue that one of the possibilities is to augment the existing IMO-GISIS database with the Sea-Web database which will be discussed in greater detail below. Next, I elaborate the ways in which future research should proceed to calibrate the expected monetary loss for each shipping route.

For future research, I plan to obtain the Automatic Identification System (AIS) data for ships which record the arrival and departure times at the ports of destination and arrival in a database known as Sea-Web database (available at www.sea-web.com). It is maintained by Lloyd's Register Fairplay and contains comprehensive data on the physical characteristics of the vessels. Based on these information, it becomes possible to tabulate the tanker, containership and bulker traffic for each grid if we assume that the ships travelled directly using the shortest route at sea between each pair of arrival and departure ports. The grids can then be divided into four types:

1) High Traffic High Risk

2) High Traffic Low Risk

3) Low Traffic High Risk

4) Low Traffic Low Risk

These four distinct typologies will help shipping companies better manage the risk at sea. A hypothetical mathematical example of the risk faced by a ship as it passes through a series of high, medium and low risk grids is given in Appendix 5.

< *Insert Appendix 5*>

My test of R1 in this dissertation was intended to augment the measurement of the harm associated with piracy to the existing algorithms utilized by the police to calibrate their targeting strategy. It could also be a helpful tool for the shipping industry and insurance companies to improve the way they currently identify the shipping routes where harm is concentrated. A relevant question worthy of future research is to examine the risk of being victimized and the expected harm faced by a ship when passing through a series of high (upper quartile in the harm per attack distribution), medium (middle-fifty in the harm per attack distribution) and low (lower quartile in the harm per attack distribution) harm grids during its journey. In Appendix 5, I provide a hypothetical example illustrating how the expected risk can be estimated. In the numeric example, the grids passed through by a ship during its journey from port A to B are known. Using the Sea-Web database mentioned earlier, it is also possible to find the denominator of the total number of ships passing through any grid at any given point in time. Therefore, the conditional probability of being attacked at any grid can be estimated by the Bayes Theorem. Given that the mean harm for each type of grid is already known, the expected harm of an attack at any grid can then be calculated. Future research can refine this analysis to estimate the expected harm at each type of grid for each type of vessel.

At least two potential policy implications arise from this example. First, for commercial vessels passing through high risk areas facing elevated expected harm, coastal law enforcement agencies may consider providing escort services in crossing these dangerous territories. As a matter a fact, such attempts have already been conducted but the results are mixed. Shortland and Vothknecht (2011) studied the effectiveness of changing the “built-environment” in the Gulf of Aden through the construction of the International Recommended Transit Corridor (IRTC) on the risk of piracyThey conducted a series of interviews with ship owners, government officials and risk consultants, noting that “it was questionable to what extent the joint naval forces patrolling the IRTC have a significant deterrent effect” (p.137). Even though more than 30 countries were represented in the IRTC, the density of warships is still not high enough to escort ships through the high risk region. Also, in general rescue efforts will not be carried out if the pirates managed to board the ship and kidnapped at least one crew member before the arrival of the naval warships. Next, the authors used logistic regression analysis to test whether the IRTC reduces the odds of piracy. Their results suggested that the IRTC actually increases the odds of pirate attacks. Their findings were in agreement with Percy and Shortland (2010), who claimed that the creation of the IRTC made shipping traffic concentrated and predictable. However, the validity of their findings is dubious as the logistic regression adopted is challenged with a variety of statistical limitations. Therefore, I recommend that future research should continue to explore using more defensible quantitative methods whether providing escorts to commercial vessels passing through HH grids facing elevated expected harm is viable.

The second agenda for future studies to address is that from the perspective of the shipping industry, what is the optimal amount ship owners should pay to avoid the monetary loss of $235,000 based on the assumption that 10 percent of the journey passes through HH grids and the probability of attack is 5 percent as shown in Appendix 5? As noted in the Introduction, several major shipping companies transfer this expected monetary loss to their customer by imposing a piracy surcharge of around $200,000 for a typical medium size container ship. Future research should aim to calibrate the expected monetary loss for each shipping route with the corresponding piracy surcharge informed by scientific evidence rather than by a general rule-of-thumb.

5.6 Final Remarks

Criminology has much to offer for the study of the causes and consequences of maritime piracy. However, previous attempts to apply criminology to maritime piracy were mostly qualitative and limited to descriptive analysis. Also few studies of maritime piracy have been informed by criminological theory. I confront these limitations by assembling a longitudinal database, applying the principals of environmental criminology, routine-activities perspective and the rational-choice theory for the case of maritime piracy, to three research questions. The first research question is an inductive exploration, by attempting to find out from a large geodatabase of pirate attacks whether there is any statistically significant patterns of spatial, as well as spatial-temporal, concentration of crime and harm. As my study protocol demonstrated, I was open to all possible types of clustering across space and time, or lack thereof. My intention in this analysis was to explore, as well as to compare and contrast piracy hot spots and harms spots across different regions of the world, how they vary over time and how they differ from their space-time neighbors. Furthermore, in the grid-level analysis I was able to demonstrate that there are a great deal of similarities between the patterns of clustering of crime at sea and what we already know on land. The theoretical relevance of my findings for environmental criminology are evaluated. A set of recommendations for current police practices are offered as part of policy implications.

The second question is based upon deductive hypothesis testing. Four hypotheses related to the three components of the routine activities perspective and their convergence in space and time were tested. I made two novel theoretical contributions based on my results, as well as two policy recommendations for the authorities in the littoral countries most affected by piracy. Likewise, for the third research question, I tested one hypothesis based on the economic model of piracy. After highlighting the merits of my contribution to the economics of crime literature, I situate my findings in the era of global warming and provide a list of recommendations to the Somali authorities, who are being adversely affected by the rise in ocean temperature.

The results of these five hypotheses remained valid through multiple methods based on very different assumptions. Despite the robustness of my findings, I highlighted the limitations of my study on several fronts including conceptual, data and methods. Last but not least, my dissertation is just the first step towards bringing the study of the causes and consequences of maritime piracy into main stream criminology. I highlighted several avenues in which the current endeavor could be broadened, both theoretically and methodologically, as well as some practical aspects of the crime for the shipping industry which future research should aim to address. It is my hope that this important but understudied topic continues to be explored by researchers using different datasets and regions not examined herein. Further research and replication, if accomplished, would enhance the internal and external validities of my findings. Regardless of the effect my results may have on guiding policy decisions and future research, they lend force to the proposal to test criminological theories in the context of maritime piracy in the same way that other criminological topics are tested.

Appendices

Appendix 1

Consider the following system of equations

$$piracy\ incidence_{i1} = z'_{i1}\beta_1 + fish_{i2}\gamma_1 + \mu_{i1}$$

$$fish_{i2} = z'_{i2}\beta_1 + piracy\ incidence_{i1}\gamma_2 + \mu_{i2}$$

where it is assume that both z_1 and z_2 are uncorrelated with both μ_1 and μ_2. This system is a structural simultaneous equation system since y_1 and y_2 are simultenously determined. The regressor $fish_2$ depends on $piracy\ incidence_1$ through the second equation. As $piracy\ incidence_1$ is directly dependent on μ_1, the regressor $fish_2$ is also correlated with μ_1 and hence endogenous in the first equation. Assuming that μ_1 and μ_2 are uncorrelated, $cov(x_{ik}, u_i) = [\gamma_2/(1-\gamma_1\gamma_2)]\sigma^2_{\mu_1}$.

The above equation system is also described as reverse causality because the dependent variable $piracy\ incidence_1$ has a feedback effect on the regressor $fish_2$. In the above system z_2 and z_1 are straightforward instruments for IV estimation of the first and second equation respectively.

Consider the true regression model which conforms to the standard OLS assumption:

$$piracy\ incidence_1 = \beta_0 + \beta_1 fish_i^* + u_i^*$$

Suppose that the variable $fish^*$ is instead observed with an error where the error v is uncorrelated with $fish^*$ and with u_i^*:

$$fish_i = fish_i^* + v_i$$

The estimated regression model uses x as a proxy for x^* where $u_i = u_i^* - \beta_1 v_i$

$$piracy\ incidence_1 = \beta_0 + \beta_1 fish_i + u_i$$

The regressor $fish$ is therefore correlated with the error term u as both depends on v. Assuming independence between v and u^*, the covariance is $cov(fish, u) = -\beta_1 \sigma_v^2$.

The OLS estimate is biased towards zero and is given by:

$$\left|plim\hat{\beta}_1\right| = |\beta_1| \frac{1}{1 + \frac{V(v_i)}{V(fish_i)}} < |\beta_1|$$

Appendix 2

An Economic Model for Hypothesis 5

Consider a pirate with an exogenous income confronted with the problem of deciding what portion of this time to allocate to the legitimate activity of fishing and the illegitimate activity of piracy. Following the notations used in Ehrlich (1973), I denote the following:

i: illegal activity (pirating);

l: legal activity (fishing);

t: proportion of time spent on a particular activity, $0 \leq t \leq 1$; $t_l > 0$; $t_i > 0$;

W^0: initial wealth;

$W_l(t_l) = F_l(t_l; \beta)$: actual income from fishing; where β is a shift parameter; and $f(\cdot) > 0$, $t_l > 0$; $f(\cdot) = 0$, $t_l = 0$; $f_t > 0$; $f_\beta > 0$; $f_{t\beta} > 0$;

$W_i(t_i) = G_i(t_i; \alpha)$: actual income from pirating; where α is a shift parameter; and $g(\cdot) > 0$, $t_i > 0$; $g(\cdot) = 0$, $t_i = 0$; $g_t > 0$; $g_\alpha > 0$; $g_{t\alpha} > 0$;

$U(W)$: the individual's von Neumann-Morgenstern utility function, $U_W > 0$, $U_{WW} < 0$;

p: the probability that the pirate is apprehended;

$H_i(t_i; \gamma)$: the monetary penalty if the pirate attack is unsuccessful;

W_S: the individual's income if the pirate attack is successful;

$$W_S \equiv W^0 + W_i(t_i) + W_l(t_l)$$

W_U: the individual's income if the pirate attack is unsuccessful;

$$W_U \equiv W^0 + W_i(t_i) + W_l(t_l) - H_i(t_i; \gamma)$$

According to this framework, the pirate's expected utility can be expressed as:

$$EU(W) = (1 - p)U(W_S) + pU(W_U) \tag{A1}$$

Assuming that leisure time is fixed so that the remaining number of hours per day has to be split between legal and illegal activities. This assumption requires that the time allocated to legal and illegal activity changes in opposite direction. For the pirate to devote some but not all of his time to piracy there must be an t^0 such that:

$$dEU(W)/dt_i = (1-p)U'(W_S)(g_t - f_t) + pU'(W_U)(g_t - f_t - h_t) = 0 \quad \text{(A2)}$$

The responses of the equilibrium portion of time devoted to piracy, t^0, to changes in the several parameters in the model are listed as follows:

$$\frac{\partial t^0}{\partial \beta} = \frac{p\left((g_t - f_t - h_t)U''(W_U)f_\beta + U'(W_U)f_{t\beta}\right)}{J_1^0} \quad \text{(A3)}$$

It can be shown that the model possesses the following qualitative properties[1] when the pirate is risk adverse:

$$\frac{\partial t^0}{\partial \beta} < 0 \quad \text{(A3a)}$$

Stated in words, any decrease in the legitimate income from fish activities will always have a negative effect in the time allocated to these activities.

[1] In equations (A3) the symbol J_1^0 represents the Jacobian associated with equilibrium condition (A2), evaluated at x^0, and is negative by hypothesis. Defining the Arrow-Pratt measure of absolute risk aversion as $R(W) \equiv -\frac{U''}{U'}$ and assuming that the potential pirate is risk averse, I adopt the usual assumption that $\frac{\partial R}{\partial W} < 0$.

Appendix 3

Chapter 3 - Bayesian Analysis

Recently, Bayesian analysis has been gaining in popularity. Sha et al. (2006) is one of the pioneering studies which applied the Bayesian approach to accelerated failure time models. In the following analysis, I follow their approach to estimate to what extent each of the three components of the routine-activity approach and their convergence influence the hazard of pirate attacks.

In the medical literature, research conducted by Bedrick et al. (2000) presented one of the earliest Bayesian approach to accelerated failure time models using Monte Carlo methods. Following the notations used in Bedrick et al (2000) and Sha et al. (2006), the likelihood function is denoted as:

$$L(\beta, \sigma|t) = \prod_{i=1}^{n} f\left(t_j \middle| \beta, \sigma\right)^{v_i} S\left(t_j \middle| x_j\right)^{1-v_i} \quad \text{(A4)}$$

As demonstrated in Carlin and Louis (2010), prior information are incorporated into the process of statistical analysis in the Bayesian framework. Priors for this model for β is given by:

$$\beta|\sigma^2 \sim \mathcal{N}_p(\beta_0, \sigma^2\Sigma_0) \quad \text{(A5)}$$

Assuming independence, the joint posterior distribution for β according to the Bayesian paradigm can be expressed as:

$$\pi(\beta, \tau|n, t, x, v) \propto L(\beta, \tau|n, t, x, v)\pi(\beta, \tau|\beta_0, \sigma^2\Sigma_0) \quad \text{(A6)}$$

Congdon (2003) and Robert, Casella and Casella (2010) illustrated that equation (19) can then be updated using the Markov chain Monte Carlo simulation algorithm through the Gibbs sampling method. Leveraging on random-walk Metropolis-Hastings sampling, the iteration process converge toward models with relatively high posterior probability based on a randomly chosen initial model (Sha et al. 2006).

Brown et al. (1998) showed that the prediction of survival times could be made through model averaging. Following the data augmentation approach of Tanner and Wong (1987) and adopted in Sha et al. (2006), let $W = (w_1, \ldots, w_j)'$ where $w_j = \ln(t_j)$ so that

$$\begin{cases} w_i = \ln\left(t_j^*\right), \delta_j = 1 \\ w_i > \ln\left(t_j^*\right), \delta_j = 0 \end{cases} \tag{A7}$$

Denoting $\widehat{W} = \frac{1}{M}\sum_{k=1}^{M} W^k$ as the augmented data with censored failure times imputed by the mean of their sampled values, and γ as the variable selection indicator in the Metropolis search, the log-normal survival time computed as the posterior mean of the predictive distribution, weighted by the posterior probabilities for a given γ is:

$$\widehat{W_f} = \sum_\gamma X_{f(\gamma)}^* \widehat{\beta_\gamma^*} \cdot p(\gamma|X, \widehat{W}) \tag{A8}$$

Here, $\widehat{\beta_*^\gamma} = (X_\gamma^{*\prime} I X_\gamma^* + \Sigma_0 \binom{*-1}{(\gamma)})^{-1}((X_\gamma^{*\prime} I X_\gamma^* + \Sigma_0 \binom{*-1}{(\gamma)} \beta_{0_\gamma}^{\ *})$ (A9)

For the subsequent analyses, I set the starting seed as “1” for replication and to improve the mixing of the MCMC algorithm, I follow Jackman (2009) and rely on the thinning approach and discard every 29 sample observations by setting thinning to be 30.

The effect of the covariate on the response is to either accelerate ($\widehat{\beta_*^\gamma} < 0$) or decelerate ($\widehat{\beta_*^\gamma} > 0$) the failure time. In equation (22), a one-unit increase in any element f in the vector X_γ^* thus induces the time to failure to increase by the factor $e^{\widehat{\beta_*^\gamma}}$. The expected time to failure can be expressed as $E\left(t_j \middle| x_j\right) = e^{\beta_0} e^{X_\gamma^* \widehat{\beta_*^\gamma}}$. That is, every one unit change in x_j corresponds to a change of $100 \times [1 - e^{\widehat{\beta_*^\gamma}}]$ percent in the expected survival time. Stated in words, a negative coefficient for each of the four hypothesis H1 – H4 would imply that the time to event (piracy attack) is accelerated, or the predicted survival time decreases, consistent with the motivation effect, targets effect, absence of guardianship effect or the convergence effect.

The Bayesian log-normal accelerated failure time survival model calculates the posterior mean probability of H_0 using the simulated posterior distributions of model parameters produced by the algorithm outlined above. Given that in the accelerated failure time model, the time to the next piracy attack is accelerated when the estimated coefficient is negative, I test the hypothesis $H_0: \theta \in (-\infty, 0)$. The robustness check results are presented in the following chapter.

Chapter 4 – Results for Bayesian Analysis

For Hypotheses 1, in the Malacca Strait, Ramadan induces the mean of the predicted survival time to be shortened by 100x[1-exp(-0.310)]=26.7 percent, and the posterior mean probability that the time to the next piracy attack is accelerated (coefficient belonging to the negative domain) during Ramadan is 96.8 percent. Similarly, in the port area and international water of the Malacca Strait, the posterior mean probability that the time to the next piracy attack is accelerated by 97.2 percent and 92.1 percent, respectively during Ramadan. In these two areas, the decrease in the mean of the predicted survival time during Ramadan is estimated to be 16.9 percent and 23.7, respectively. In the South China Sea, Hypotheses 1 is most strongly supported in the port area as depicted in Table 14. The posterior mean probability that Ramadan accelerates the failure time (time to the next piracy attack) is 94.8 percent, and the mean of the predicted survival time decreases by 14.9 percent during Ramadan.

In Hypothesis 2, I predict that the hazard of piracy will increase when the capable guardians are absent. Consistent with this prediction, in Table 13 it is shown that during the period when MALSINDO is not in operation in the Malacca Strait, there is a 99.8 percent chance that the time to the next piracy attack is accelerated in international water, and it induces the mean of the predicted survival time to be shortened by 32.2 percent. For the variable "Regional Military Expenditure", the probability for the estimated coefficient to be negative for every one-unit decrease is 100 percent for the entire Malacca Strait, territorial water and international water. The reduction in the mean of the predicted survival time associated with every one-unit decrease for these areas are 69 percent, 71.5 percent and 74.4 percent, respectively. In the South China Sea, Hypotheses 2 remain strongly supported. Table 14 shows that when MALSINDO is not in operation in the region, the posterior mean probability that the absence of MALSINDO accelerates the failure time (time to the next piracy attack) is 95.3 percent and 99.2 percent for all areas and international water, respectively, while the reduction in the mean of the predicted survival time are 15.4 percent and 41.7 percent in the same places when MALSINDO is not in operation. Similarly, in the absence of CARAT, the posterior mean probability that the time to the next piracy attack is accelerated is 98.5 percent and 99.8 percent for all areas and international water, respectively. In the same places, the mean of the predicted survival time are 10.8 percent and 29.4 percent shorter. The absence of regional military expenditure provides the strongest support of H2. The posterior mean probability for the estimated coefficient to be negative for every one-unit decrease in the regional military expenditure is 100 percent for the entire Malacca Strait, territorial water, port area and international water. The reduction in the mean of the predicted survival time associated with every one-unit decrease for these areas are 55.7 percent, 53.5 percent, 55.2 percent and 65.9 percent, respectively.

Hypothesis 3 examines the attractiveness of targets, which predicts that the hazard of piracy will increases when the value of trade passing through the region is high. Table 14 exhibits evidence in support of H3. For every unit increase in the value of regional trade, the posterior mean probability that the estimated coefficient is negative is 98.1 and 98.7 for all areas and international water. It is estimated that for every unit increase in the regional trade in the South China Sea, the predicted mean survival time decreases by 18.1 percent for all areas and 36.8 percent in international water. However, there is no evidence supporting H3 in the Malacca Strait.

<Insert Figure 19>

<Insert Figure 20>

<Insert Figure 21>

To maximize confidence in the results for H1 – H3, I next show the trace, autocorrelation and density plots for piracy attacks in Malacca Strait for all areas, territorial water, and port area in Figures 19, 20, and 21. Visual inspection of the trace plot is relied upon to assess whether the MCMC chain mixed well. The trace of the variables shown in these Figures suggests that convergence is achieved in all areas, territorial water, and port area. An alternative way to check for convergence is through visual inspection of the autocorrelation plot of the MCMC samples. Given that the autocorrelation becomes almost negligible after about 10 lags for most of the variables, I again confirm that convergence is achieved. Therefore, the results obtained for all areas, territorial water, and port area in Table 13 are fairly reliable.

<Insert Figure 22>

In Figure 22, visual inspection of the trace and autocorrelation plots indicates that convergence for the variables "MALSINDO", "Regional Military Expenditure" and "Regional Trade" seems to be weak for international water. The degree of correlation between the MCMC samples seems high and mixing is slow. This suggests that the validity of the findings for the variables "MALSINDO" and "Regional Military Expenditure" in Table 8 should be interpreted with caution.

For South China Sea, visual inspection of the trace plot and autocorrelation plot for all areas, territorial water, port area and international water in Figures 23, 24, 25 and 26 indicate that convergence is achieved. On the other hand, visual inspection of Figure 25 suggests that the MCMC chain did not mix well for the variables "MALSINDO", "Regional Military Expenditure" and "Regional Trade" in the port area of South China Sea. According to these figures, I conclude that the validity of the findings in Table 14 for all areas, territorial water, and international water are fairly strong, while that of "Regional Military Expenditure" in the port area appears to be less reliable.

<Insert Figure 23>

<Insert Figure 24>

<Insert Figure 25>

<Insert Figure 26>

<Insert Figure 27>

The results for Hypothesis 4 which predicts that the hazard of piracy will increase when measures of absence of capable guardian converge with the measures of motivated pirates and suitable targets is presented in Table 15. Consistent with the prediction, the convergent effect induces the mean of the predicted survival time to be shortened by 46 percent and 18.8 percent, while the posterior mean probability that the time to the next piracy attack is accelerated is 100 percent and 100 percent for the Malacca Strait and South China Sea, respectively. Given that visual inspection of the trace and autocorrelation plots of the convergence term indicates convergence of the MCMC samples and fast mixing as shown in Figure 27, the results for H4 are fairly reliable.

Appendix 4

Chapter 4 – Results for Two-stage Cox Proportional Hazards Models

The evidence in support of Hypothesis 5 which states that the hazard of piracy is inversely related to the fish capture production is shown in Table 19. The hazard ratio for the independent variable “Fish Capture Production” demonstrates that the hazard of illegal activities (piracy) is inversely related to legal (fishing) activities. Specifically, for every one million tons increase in fish output, the risk of being attacked drops by about 38.1 percent and 0.5 percent in East Africa and Malacca Strait and South China Sea combined, respectively. As before, I instrument the endogenous variable fish capture production with the SST measure to tackle the problem of endogeneity. The hazard ratio in the two-stage Cox proportional hazards models for the two regions are reported in Table 20. Even after instrumenting fish output with SST, the conclusion that the hazard of illegal activities (piracy) is inversely related to legal (fishing) activities remains unchanged. In East Africa, however, the hazard of piracy decreases by 90.5 percent for every one million tons increase in fish output; while that of the and Malacca Strait and South China Sea combined drops by 6.9 percent. Similar to the case of the semiparametric additive hazards models, employing the instrumental variable approach yields a substantially larger reduction in hazards across both regions.

Of fundamental interest is whether the results going from the semiparametric additive hazards model to the Cox proportional hazards model remain robust. The results presented above clearly indicate that the Cox proportional hazards model coefficients in Table 20 corroborate with the semiparametric additive hazards model’s finding: The hazard of piracy is inversely related to fish output production. This finding remains valid even after instrumenting fish output production by SST in both sets of models.

<Insert Table 19>

<Insert Table 20>

Appendix 5

Chapter 5 Discussion and Conclusion

Suppose a ship going from port A to B passes through 10% high harm (HH) grids, 20% medium harm (MH) grids and 70% low harm (LH) grids. The probability of being attacked is 5% at HH, 3% at MH and 1% at LH. Given that the ship is attacked during the journey, what is the probability that it was perpetuated in HH, MH and LH? Find the expected harm at each type of grid.

Let random variable X denote the event that the ship is passing through the ith grid where i=HH, MH, LH

Let random variable Y denote the event that a ship is attacked

$$P(X_{HH}) = 0.1;\ P(X_{MH}) = 0.2;\ P(X_{LH}) = 0.7$$

$$P(Y|X_{HH}) = 0.05;\ P(Y|X_{MH}) = 0.03;\ P(Y|X_{LH}) = 0.01$$

$$P(Y) = \sum_i P(Y|X_i)P(X_i) = 0.018$$

$$P(X_{HH}|Y) = \frac{P(Y|X_{HH})P(X_{HH})}{P(Y)} = 0.278$$

$$P(X_{MH}|Y) = \frac{P(Y|X_{MH})P(X_{MH})}{P(Y)} = 0.333$$

$$P(X_{LH}|Y) = \frac{P(Y|X_{LH})P(X_{LH})}{P(Y)} = 0.389$$

At the grid level, the upper and lower quartile for the harm per attack are 9335 and 236 CHI days respectively. It follows that harm per attack at HH, MH and LH are 9335, 2536 and 236 CHI days.

Expected harm at HH is $P(X_{HH}|Y) * Harm_{HH} = 0.278 * 9335 = 2595$ CHI days

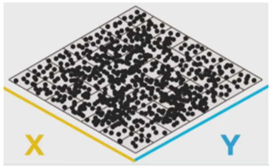
Expected harm at MH is $P(X_{MH}|Y) * Harm_{MH} = 0.333 * 2536 = 844$ CHI days

Expected harm at LH is $P(X_{LH}|Y) * Harm_{LH} = 0.389 * 236 = 92$ CHI days

The estimated cost to house inmate is around \$33,000 per annum (Vera Institute, 2017). Using this estimate, the expected monetary loss associated with an attack at HH, MH and LH is approximately \$235,000, \$76,300 and \$8,300, respectively.

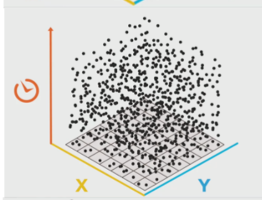
Table 1. Data Preprocessing Scheme in ArcMap 10.5

Step A



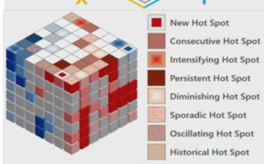
Spatial Point Data

Step B



Aggregating Spatial-Temporal Data into Bins

Step C



- New: the most recent time step interval is hot for the first time
- Consecutive: a single uninterrupted run of hot time step intervals, comprised of less than 90% of all intervals
- Intensifying: at least 90% of the time step intervals are hot, and becoming hotter over time
- Persistent: at least 90% of the time step intervals are hot, with no trend up or down
- Diminishing: at least 90% of the time step intervals are hot, and becoming less hot over time
- Sporadic: some of the time step intervals are hot
- Oscillating: some of the time step intervals are hot, some are cold

Step D

- High-High Cluster: Z-Score in bin is higher than other bins, neighborhood is higher than other neighborhoods
- High-Low Outlier: Z-Score in bin is higher than other bins, neighborhood is lower than other neighborhoods
- Low-High Outlier: Z-Score in bin is lower than other bins, neighborhood is higher than other neighborhoods
- Low-Low Cluster: Z-Score in bin is lower than other bins, neighborhood is lower than other neighborhoods

Table 2. Descriptive Statistics, Piracy Attacks in Malacca Strait and South China Sea, 1995 to 2010

	Malacca Strait				*South China Sea*			
	Mean	Standard Deviation	Minimum Value	Maximum Value	Mean	Standard Deviation	Minimum Value	Maximum Value
Dependent Variable								
Days until next attack	11.817	22.652	1	289	4.178	4.143	1	37
Independent Variable								
Convergence								
Motivation*Absence of Capable Guardian*Suitable Target[a]	0.450	0.498	0	1	0.352	0.478	0	1
Motivation[b]								
Regional Misery Index	16.717	4.588	10.504	47.178	8.890	2.685	4.159	14.143
Regional Misery Index (Dichotomized at Median)	0.539	0.499	0	1	0.581	0.494	0	1
During Ramadan	0.108	0.310	0	1	0.110	0.312	0	1
Absence of Capable Guardian[c]								
MALSINDO	0.879	0.327	0	1	0.695	0.460	0	1
CARAT	0.856	0.352	0	1	0.826	0.379	0	1
Regional Military Expenditure	-1.058	0.252	-1.469	-0.792	-1.832	0.116	-2.037	-1.637
Regional Military Expenditure (Dichotomized at Median)	0.502	0.501	0	1	0.533	0.499	0	1
Suitable Target								
Regional Trade	1.154	0.341	0.789	2.418	1.201	0.542	0.676	2.448
Regional Trade (Dichotomized at Median)	0.630	0.483	0	1	0.511	0.500	0	1
Context								
Success Density[d]	34.669	57.102	0	365	69.227	79.226	0	365
Last Reported	0.759	0.429	0	1	0.715	0.451	0	1

[a] Sample size=197 for Malacca Strait and 590 for South China Sea; Convergence=0 if at least one of its components=0 and Convergence=1 otherwise

[b] Motivation=1 if at least one of its components=1;

[c] Absence of capable guardian=1 if at least one of its components=1;

[d] $\frac{P(\text{success for current and two previous attempts})}{(\text{event date}_{\text{current}} - \text{event date}_{\text{second previous}})/365}$

Table 3. AFT Regression Model Selection: Akaike (AIC) and Bayesian (BIC) Information Criteria

		Malacca Strait *n=438*		*South China Sea* *n=1676*	
Model (distr.)	d.f.	AIC	BIC	AIC	BIC
Exponential	9	1301.755	1338.287	4390.454	4439.169
Weibull	10	1303.549	1344.14	4220.43	4274.557
Log-normal	10	1246.913	1287.504	4009.723	4063.85
Log-logistic	10	1256.271	1296.862	4113.164	4167.292

Note: AIC and BIC refers to the Akaike and the Bayesian Information Criteria, while d.f. refers to the number of degrees of freedom in the Maximum Likelihood estimations.
All of the underlying regressions include the full set of controls.

Table 4. Descriptive Statistics for Piracy Attacks in East Africa, 2002 to 2013

	Mean	Std. Dev.	Min	Max
Dependent Variable				
Days until next attack	4.984	9.847	1	111
Instrument				
Sea Surface Temperature (# of std dev)	0.909	0.478	-0.574	2.109
Independent Variables				
Fish Capture Production	6.076	0.276	5.017	6.576
Regional Misery Index	94.775	12.270	66.628	117.354
Regional Trade	2.445	0.529	0.914	3.100
Merchant Ships[a]	0.855	0.352	0	1
Context				
Success Density[b]	18.604	42.600	0	365
Last Reported	0.817	0.387	0	1

[a] Merchant ships consist of container ships, cargo carriers and tankers.

[b] $\frac{P(\text{success for current and two previous attempts})}{(\text{event date}_{current} - \text{event date}_{second\ previous})/365}$

Table 5. Emerging Hot Spot Analysis for Piracy Attacks, 2006 to 2014

Type of Hot Spot	World		East Africa		Malacca Strait & South China Sea	
	Frequency	*Harm*	*Frequency*	*Harm*	*Frequency*	*Harm*
New	0	0	3	2	0	0
Consecutive	19	14	0	0	4	4
Intensifying	0	0	0	0	0	0
Persistent	0	0	0	0	0	0
Diminishing	5	0	0	0	0	0
Sporadic	0	17	0	2	32	34
Oscillating	0	0	0	0	0	0
Historical	0	0	0	0	0	0

Table 6. Local Outlier Analysis in All Locations for Piracy Attacks, 2006 to 2014

Category	World		East Africa		Malacca Strait & South China Sea	
	Frequency # of Locations (%)	*Harm* # of Locations (%)	*Frequency* # of Locations (%)	*Harm* # of Locations (%)	*Frequency* # of Locations (%)	*Harm* # of Locations (%)
Never Significant	76 (22.29%)	96 (28.51%)	117 (29.85%)	55 (14.03%)	65 (45.14%)	81 (56.25%)
Only high-high cluster	9 (2.64%)	3 (0.88%)	1 (0.26%)	6 (1.53%)	4 (2.78%)	5 (3.47%)
Only low-high outlier	16 (4.69%)	13 (3.81%)	9 (2.3%)	58 (14.80%)	14 (9.72%)	24 (16.67%)
Only low-low cluster	87 (25.51%)	151 (44.28%)	83 (21.17%)	67 (17.09%)	8 (5.56%)	2 (1.39%)
Only high-low outlier	43 (12.61%)	21 (6.16%)	25 (6.38%)	5 (1.28%)	35 (24.31%)	22 (15.28%)
Multiple Types	110 (32.26%)	57 (16.72%)	157 (40.05%)	201 (51.28%)	18 (12.50%)	10 (6.94%)

Table 7. Local Outlier Analysis in the Entire Space Time Cube for Piracy Attacks, 2006 to 2014

Category	World		East Africa		Malacca Strait & South China Sea	
	Frequency	*Harm*	*Frequency*	*Harm*	*Frequency*	*Harm*
	# of Bins (%)	# of Bins (%)	# of Bins (%)	# of Bins (%)	# of Bins (%)	# of Bins (%)
High-low outlier	101 (1.85%)	40 (0.73%)	48 (0.77%)	19 (0.30%)	39 (1.69%)	24 (1.04%)
Low-high outlier	283 (5.19%)	314 (5.76%)	335 (5.34%)	492 (7.84%)	111 (4.82%)	64 (2.78%)
High-high cluster	199 (3.65%)	150 (2.75%)	204 (3.25%)	157 (2.50%)	39 (1.69%)	20 (0.87%)
Low-low cluster	997 (18.27%)	860 (15.76%)	933 (14.88%)	1098 (17.51%)	12 (0.52%)	4 (0.17%)
Not Significant	3876 (71.04%)	4092 (75%)	4752 (75.77%)	4506 (71.84%)	2103 (91.28%)	2192 (95.14%)

Table 8. Hazard Ratios and Robust Standard Errors for Series Hazard Models, Piracy Attacks in Malacca Strait by Place, 1995 to 2010

Independent Variable	All *n=438*	Territorial Water *n=118*	International Water *n=251*	Port *n=71*
	Hazard Ratio (Clustered Robust Standard Error)			
Motivation				
Regional Misery Index	0.988	0.974	0.992	1.189**
	(0.012)	(0.018)	(0.015)	(0.073)
During Ramadan	1.365*	0.797	1.258	3.483*
	(0.190)	(0.180)	(0.233)	(2.102)
Absence of Capable Guardian				
MALSINDO	3.551**	7.534†	3.522**	3.530
	(0.926)	(8.968)	(1.045)	(3.248)
CARAT	0.964	1.167	0.823	0.716
	(0.119)	(0.343)	(0.153)	(0.200)
Regional Military Expenditure	3.520**	3.736*	4.449**	1.293
	(0.958)	(2.540)	(1.520)	(1.144)
Suitable Target				
Regional Trade	2.547**	6.611†	1.784†	1.237
	(0.751)	(7.399)	(0.629)	(1.295)
Context				
Success Density	1.012**	1.021**	1.011**	1.019**
	(0.001)	(0.004)	(0.001)	(0.003)
Last Reported	1.243†	1.323	1.460*	1.420
	(0.150)	(0.305)	(0.266)	(0.500)

†$p \leq 0.10$ *$p \leq 0.05$ **$p \leq 0.01$, all two-tailed tests

Table 9. Hazard Ratios and Robust Standard Errors for Series Hazard Models, Piracy Attacks in South China Sea by Place, 1995 to 2010

Independent Variable	All *n=1676*	Territorial Water *n=750*	International Water *n=352*	Port *n=574*
	Hazard Ratio (Clustered Robust Standard Error)			
Motivation				
Regional Misery Index	0.976*	0.983	0.929**	0.989
	(0.101)	(0.013)	(0.021)	(0.025)
During Ramadan	1.074	1.008	0.985	1.232
	(0.083)	(0.109)	(0.162)	(0.188)
Absence of Capable Guardian				
MALSINDO	1.563**	1.886**	2.399**	1.203
	(0.195)	(0.474)	(0.708)	(0.205)
CARAT	1.161**	1.177†	1.438**	0.988
	(0.070)	(0.114)	(0.187)	(0.101)
Regional Military Expenditure	0.848	0.518	4.222*	1.930
	(0.232)	(0.238)	(2.700)	(0.964)
Suitable Target				
Regional Trade	1.370**	1.487*	2.153**	0.974
	(0.154)	(0.297)	(0.551)	(0.193)
Context				
Success Density	1.008**	1.008**	1.007**	1.009**
	(0.000)	(0.001)	(0.001)	(0.001)
Last Reported	0.957	0.982	1.178	1.283†
	(0.064)	(0.086)	(0.158)	(0.176)

†$p \leq 0.10$ *$p \leq 0.05$ **$p \leq 0.01$, all two-tailed tests

Table 10. Hazard Ratios and Robust Standard Errors for Series Hazard Models, Convergent Effect for Piracy Attacks in Malacca Strait and South China Sea, 1995 to 2010

Independent Variable	Malacca Strait *n=438*	South China Sea *n=1676*
	Hazard Ratio (Clustered Robust Standard Error)	
Convergence		
Motivation*Absence of Capable Guardian*Suitable Target	1.749**	1.234*
	(0.227)	(0.118)
Motivation		
Regional Misery Index	0.980†	0.964**
	(0.012)	(0.018)
During Ramadan	1.235	1.035
	(0.176)	(0.081)
Absence of Capable Guardian		
MALSINDO	2.854**	1.603**
	(0.726)	(0.198)
CARAT	0.973	1.165**
	(0.115)	(0.071)
Regional Military Expenditure	3.662**	0.858
	(0.994)	(0.236)
Suitable Target		
Regional Trade	1.315	1.262*
	(0.417)	(0.147)
Context		
Success Density	1.012**	1.008**
	(0.001)	(0.000)
Last Reported	1.284**	0.921
	(0.155)	(0.064)

†$p \leq 0.10$ *$p \leq 0.05$ **$p \leq 0.01$, all two-tailed tests

Table 11. Coefficient and Robust Standard Errors for Accelerated Failure Time Models, Convergent Effect for Piracy Attacks in Malacca Strait, 1995 to 2010

	Exponential	Weibull	Log-Normal	Log-Logistic
Independent Variable	Coefficient (Clustered Robust Standard Error)			
Convergence				
Motivation*Absence of Capable Guardian*Suitable Target	-0.931**	-0.936**	-0.597**	-0.586**
	(0.118)	(0.117)	(0.114)	(0.127)
Motivation				
Regional Misery Index	0.053**	0.052**	0.034*	0.034†
	(0.014)	(0.013)	(0.016)	(0.019)
During Ramadan	-0.231	-0.232†	-0.182	-0.155
	(0.143)	(0.142)	(0.144)	(0.161)
Absence of Capable Guardian				
MALSINDO	-0.231*	-0.414*	-0.142	-0.196
	(0.143)	(0.190)	(0.203)	(0.234)
CARAT	0.216	0.218	0.122	0.106
	(0.144)	(0.143)	(0.136)	(0.140)
Regional Military Expenditure	-1.762**	-1.773**	-1.000**	-0.994**
	(0.318)	(0.314)	(0.293)	(0.328)
Suitable Target				
Regional Trade	0.506	0.502†	0.694*	0.714*
	(0.291)	(0.290)	(0.308)	(0.351)
Context				
Success Density	-0.009**	-0.009**	-0.008**	-0.008**
	(0.000)	(0.000)	(0.000)	(0.000)
Last Reported	-0.347**	-0.348*	-0.252	-0.194
	(0.144)	(0.145)	(0.127)	(0.140)

†$p \leq 0.10$ *$p \leq 0.05$ **$p \leq 0.01$, all two-tailed tests

Table 12. Coefficients and Robust Standard Errors for Accelerated Failure Time Models, Convergent Effect for Piracy Attacks in South China Sea, 1995 to 2010

Independent Variable	Exponential	Weibull	Log-Normal	Log-Logistic
	Coefficient (Clustered Robust Standard Error)			
Convergence				
Motivation*Absence of Capable Guardian*Suitable Target	-0.257**	-0.264**	-0.206**	-0.233**
	(0.084)	(0.086)	(0.080)	(0.090)
Motivation				
Regional Misery Index	0.050**	0.051**	0.042**	0.045**
	(0.011)	(0.012)	(0.010)	(0.011)
During Ramadan	-0.013	-0.008	-0.030	-0.035
	(0.070)	(0.073)	(0.064)	(0.074)
Absence of Capable Guardian				
MALSINDO	-0.290**	-0..301**	-0.238**	-0.271**
	(0.104)	(0.107)	(0.100)	(0.114)
CARAT	-0.107*	-0.103†	-0.113*	-0.115*
	(0.055)	(0.056)	(0.053)	(0.059)
Regional Military Expenditure	-0.954**	-1.005	-0.770**	-0.787**
	(0.103)	(0.105)	(0.098)	(0.112)
Suitable Target				
Regional Trade	-0.165†	-0.177†	-0.149	-0.164
	(0.154)	(0.101)	(0.097)	(0.111)
Context				
Success Density	-0.006**	-0.006**	-0.004**	-0.005**
	(0.000)	(0.000)	(0.000)	(0.000)
Last Reported	-0.020	-0.010	-0.053	-0.062
	(0.057)	(0.060)	(0.052)	(0.058)

†$p \leq 0.10$ *$p \leq 0.05$ **$p \leq 0.01$, all two-tailed tests

Table 13. Posterior Estimated Mean and Posterior Mean Probability for Bayesian Log-Normal Accelerated Failure Time Survival Models, Piracy Attacks in Malacca Strait by Place, 1995 to 2010

	All		Territorial Water		Port		International Water	
	n=428		*n=114*		*n=68*		*n=245*	
Independent Variable	Mean[a,b]	Posterior Mean Pr. $H_0: \theta \in (-\infty, 0)$	Mean[a,c]	Posterior Mean Pr. $H_0: \theta \in (-\infty, 0)$	Mean[a,d]	Posterior Mean Pr. $H_0: \theta \in (-\infty, 0)$	Mean[a,e]	Posterior Mean Pr. $H_0: \theta \in (-\infty, 0)$
Motivation								
Regional Misery Index	0.026	0.009	0.031	0.063	-0.045	0.742	0.027	0.020
	(0.011)	(0.095)	(0.019)	(0.243)	(0.070)	(0.437)	(0.013)	(0.140)
During Ramadan	-0.310	0.968	0.260	0.219	-0.1849	0.972	-0.270	0.921
	(0.168)	(0.177)	(0.338)	(0.413)	(0.971)	(0.166)	(0.194)	(0.270)
Absence of Capable Guardian								
MALSINDO	-0.012	0.524	0.099	0.416	0.765	0.141	-0.388	0.998
	(0.178)	(0.499)	(0.444)	(0.493)	(0.733)	(0.348)	(0.144)	(0.047)
CARAT	0.241	0.045	0.004	0.499	0.506	0.106	0.319	0.030
	(0.141)	(0.207)	(0.362)	(0.500)	(0.406)	(0.307)	(0.173)	(0.171)
Regional Military Expenditure	-1.168	1.000	-1.255	1.000	-0.351	0.640	-1.360	1.000
	(0.278)	(0.000)	(0.658)	(0.000)	(1.018)	(0.480)	(0.221)	(0.000)
Suitable Target								
Regional Trade	-0.256	0.160	0.159	0.386	0.906	0.217	0.129	0.294
	(0.255)	(0.367)	(0.578)	(0.487)	(1.188)	(0.412)	(0.249)	(0.456)
Context								
Success Density	-0.009		-0.012		-0.012		-0.007	
	(0.000)		(0.007)		(0.007)		(0.001)	
Last Reported	-0.246		-0.459		0.031		-0.245	
	(0.131)		(0.252)		(0.563)		(0.163)	

[a] Thinning = 30; discarding every 29 sample observations. Markov Chain Monte Carlo iterations = 302,471. Seed = 1
[b] Average efficiency=0.472
[c] Average efficiency=0.346
[d] Average efficiency=0.301
[e] Average efficiency=0.159

Table 14. Posterior Estimated Mean and Posterior Mean Probability for Bayesian Log-Normal Accelerated Failure Time Survival Models, Piracy Attacks in South China Sea by Place, 1995 to 2010

	All *n=1676*		Territorial Water *n=741*		Port *n=567*		International Water *n=348*	
Independent Variable	Mean[a,b]	Posterior Mean Pr. $H_0: \theta \in (-\infty, 0)$	Mean[a,c]	Posterior Mean Pr. $H_0: \theta \in (-\infty, 0)$	Mean[a,d]	Posterior Mean Pr. $H_0: \theta \in (-\infty, 0)$	Mean[a,e]	Posterior Mean Pr. $H_0: \theta \in (-\infty, 0)$
Motivation								
Regional Misery Index	0.030	0.000	0.029	0.005	0.011	0.267	0.050	0.002
	(0.008)	(0.000)	(0.011)	(0.067)	(0.018)	(0.443)	(0.018)	(0.042)
During Ramadan	-0.062	0.827	-0.038	0.652	-0.161	0.948	0.030	0.424
	(0.065)	(0.378)	(0.097)	(0.477)	(0.100)	(0.221)	(0.146)	(0.494)
Absence of Capable Guardian								
MALSINDO	-0.167	0.953	-0.073	0.668	-0.112	0.862	-0.522	0.992
	(0.096)	(0.211)	(0.166)	(0.473)	(0.103)	(0.345)	(0.211)	(0.088)
CARAT	-0.114	0.985	-0.098	0.884	-0.003	0.524	-0.348	0.998
	(0.053)	(0.120)	(0.083)	(0.321)	(0.077)	(0.499)	(0.122)	(0.004)
Regional Military Expenditure	-0.815	1.000	-0.771	1.000	-0.802	1.000	-1.076	1.000
	(0.096)	(0.000)	(0.163)	(0.000)	(0.108)	(0.000)	(0.200)	(0.000)
Suitable Target								
Regional Trade	-0.200	0.981	-0.141	0.812	-0.042	0.620	-0.459	0.987
	(0.094)	(0.136)	(0.160)	(0.391)	(0.129)	(0.486)	(0.198)	(0.115)
Context								
Success Density	-0.005		-0.005		-0.005		-0.004	
	(0.000)		(0.000)		(0.000)		(0.000)	
Last Reported	-0.095		-0.133		-0.206		-0.174	
	(0.005)		(0.069)		(0.101)		(0.110)	

[a] Thinning = 30; discarding every 29 sample observations. Markov Chain Monte Carlo iterations = 302,471. Seed = 1
[b] Average efficiency=0.324
[c] Average efficiency=0.355
[d] Average efficiency=0.181
[e] Average efficiency=0.401

Table 15. Posterior Estimated Mean and Posterior Mean Probability for Bayesian Log-Normal Accelerated Failure Time Survival Models, Convergent Effect for Piracy Attacks in South China Sea, 1995 to 2010

	Malacca Strait *n=428*		South China Sea *n=1676*	
Independent Variable	Mean[a,b]	Posterior Mean Pr. $H_0: \theta \in (-\infty, 0)$	Mean[a,c]	Posterior Mean Pr. $H_0: \theta \in (-\infty, 0)$
Convergence				
Motivation*Absence of Capable Guardian*Suitable Target	-0.615	1.000	-0.208	0.995
	(0.132)	(0.000)	(0.079)	(0.067)
Motivation				
Regional Misery Index	0.037		0.042	
	(0.011)		(0.009)	
During Ramadan	-0.169		-0.034	
	(0.168)		(0.065)	
Absence of Capable Guardian				
MALSINDO	-0.202		-0.229	
	(0.166)		(0.097)	
CARAT	0.069		-0.118	
	(0.134)		(0.053)	
Regional Military Expenditure	-1.174		-0.760	
	(0.199)		(0.094)	
Suitable Target				
Regional Trade	0.595		-0.137	
	(0.252)		(0.096)	
Context				
Success Density	-0.008		-0.005	
	(0.000)		(0.000)	
Last Reported	-0.263		-0.051	
	(0.128)		(0.051)	

[a] Thinning = 30; discarding every 29 sample observations. Markov Chain Monte Carlo iterations = 302,471. Seed = 1
[b] Average efficiency=0.323
[c] Average efficiency=0.206

Table 16. First-stage OLS Regressions, Mean Centered, Piracy Attacks in East Africa (2002 to 2013) and Malacca Strait and South China Sea Combined (1995 to 2007)

Dependent Variable	Fish Capture Production			
	Model 1		Model 2	
	East Africa	Malacca Strait & South China Sea	East Africa	Malacca Strait & South China Sea
	Coefficient (Standard Error)			
Instrument				
Sea Surface Temperature (# of std dev)	-0.157**	1.250**	-0.165**	11.27**
	(0.017)	(0.287)	(0.016)	(0.649)
Control				
Regional Misery Index			0.003**	0.143
			(0.001)	(0.186)
During Ramadan				-1.354
				(1.682)
Absence of MALSINDO				-15.267**
				(2.601)
Absence of CARAT				1.789
				(1.377)
Low Regional Military Expenditure				6.071
				(4.632)
Regional Trade			0.200**	-44.276**
			(0.014)	(3.089)
Merchant Ship			-0.032	
			(0.021)	
Context				
Success Density			0.000†	-0.003
			(0.000)	(0.000)
Last Reported			0.049**	6.952**
			(0.019)	(1.306)

†$p \leq 0.10$ *$p \leq 0.05$ **$p \leq 0.01$, all two-tailed tests

Table 17. Semiparametric Additive Hazards Models, Mean Centered, Piracy Attacks in East Africa (2002 to 2013) and Malacca Strait and South China Sea Combined (1995 to 2007)

Dependent Variable	Days Until Next Attack			
	Model 1[a]		Model 2[b]	
	East Africa	Malacca Strait & South China Sea	East Africa	Malacca Strait & South China Sea
	Change in Hazard (Robust Standard Error)			
Independent Variable				
Fish Capture Production	-0.0609**	-0.00158*	-0.0614**	-0.00177**
	(0.009)	(0.001)	(0.009)	(0.001)
Control				
Regional Misery Index	0.090**	-0.005*	0.091**	-0.004*
	(0.011)	(0.002)	(0.011)	(0.002)
During Ramadan		0.013		0.013
		(0.026)		(0.026)
Absence of MALSINDO		0.130**		0.138**
		(0.038)		(0.038)
Absence of CARAT		0.054**		0.051**
		(0.017)		(0.017)
Low Regional Military Expenditure		0.109†		0.117†
		(0.066)		(0.066)
Regional Trade	0.001	0.101*	0.001	0.105**
	(0.000)	(0.042)	(0.000)	(0.042)
Merchant Ship	0.021		0.021	
	(0.015)		(0.015)	
Context				
Success Density	0.004**	0.003**	0.004**	0.003**
	(0.001)	(0.000)	(0.001)	(0.000)
Last Reported	-0.029	0.039*	-0.030	0.043*
	(0.022)	(0.019)	(0.022)	(0.019)

†$p \leq 0.10$ *$p \leq 0.05$ **$p \leq 0.01$, all two-tailed tests
[a] Number of simulations in resampling=0
[b] Number of simulations in resampling=1,000,000

Table 18. Two-stage Semiparametric Additive Hazards Models, Mean Centered, Piracy Attacks in East Africa (2002 to 2013) and Malacca Strait and South China Sea Combined (1995 to 2007)

Dependent Variable	Days Until Next Attack			
	Model 1[a]		Model 2[b]	
	East Africa	Malacca Strait & South China Sea	East Africa	Malacca Strait & South China Sea
	Change in Hazard (Robust Standard Error)			
Instrument				
Sea Surface Temperature (# of std dev)	-0.0616**	-0.0199**	-0.0604**	-0.0215**
	(0.093)	(0.008)	(0.093)	(0.008)
Control				
Regional Misery Index	0.201**	-0.001	0.199**	-0.002
	(0.023)	(0.003)	(0.023)	(0.002)
During Ramadan		0.007		0.001
		(0.026)		(0.026)
Absence of MALSINDO		0.050		0.039**
		(0.055)		(0.055)
Absence of CARAT		0.056**		0.054**
		(0.017)		(0.017)
Low Regional Military Expenditure		-0.028		-0.047†
		(0.085)		(0.085)
Regional Trade	0.003**	-0.109	0.003**	-0.133†
	(0.001)	(0.106)	(0.001)	(0.106)
Merchant Ship	0.004		0.003	
	(0.015)		(0.015)	
Context				
Success Density	0.004**	0.003**	0.004**	0.003**
	(0.001)	(0.000)	(0.001)	(0.000)
Last Reported	0.004	0.089**	0.002	0.091**
	(0.023)	(0.027)	(0.023)	(0.027)

†$p \leq 0.10$ *$p \leq 0.05$ **$p \leq 0.01$, all two-tailed tests
[a] Number of simulations in resampling=0
[b] Number of simulations in resampling=10,000

Table 19. Cox Proportional Hazards Models, Mean Centered, Piracy Attacks in East Africa (2002 to 2013) and Malacca Strait and South China Sea Combined (1995 to 2007)

Dependent Variable	Days Until Next Attack	
	East Africa	Malacca Strait & South China Sea
	Hazard Ratio (Robust Standard Error of Coef.)	
Independent Variable		
Fish Capture Production	0.619**	0.995*
	(0.102)	(0.002)
Control		
Regional Misery Index	1.003	0.984*
	(0.002)	(0.008)
During Ramadan		1.038
		(0.079)
Absence of MALSINDO		1.674**
		(0.129)
Absence of CARAT		1.193**
		(0.064)
Low Regional Military Expenditure		1.427†
		(0.194)
Regional Trade	1.743**	1.459**
	(0.066)	(0.147)
Merchant Ship	1.152†	
	(0.088)	
Context		
Success Density	1.008**	1.007**
	(0.001)	(0.000)
Last Reported	0.852*	1.125*
	(0.082)	(0.061)

†$p \leq 0.10$ *$p \leq 0.05$ **$p \leq 0.01$, all two-tailed tests

Table 20. Two-stage Cox Proportional Hazards Models, Mean Centered, Piracy Attacks in East Africa (2002 to 2013) and Malacca Strait and South China Sea Combined (1995 to 2007)

Dependent Variable	Days Until Next Attack	
	East Africa	Malacca Strait & South China Sea
	Hazard Ratio (Robust Standard Error of Coef.)	
Instrument		
Sea Surface Temperature (# of std dev)	0.095**	0.931**
	(0.403)	(0.023)
Control		
Regional Misery Index	1.011**	0.996
	(0.003)	(0.009)
During Ramadan		1.024
		(0.073)
Absence of MALSINDO		1.226
		(0.204)
Absence of CARAT		1.193**
		(0.074)
Low Regional Military Expenditure		0.868
		(0.219)
Regional Trade	2.401**	0.665
	(0.095)	(0.210)
Merchant Ship	1.069	
	(0.088)	
Context		
Success Density	1.007**	1.007**
	(0.001)	(0.000)
Last Reported	0.949	1.343**
	(0.085)	(0.120)

†$p \leq 0.10$ *$p \leq 0.05$ **$p \leq 0.01$, all two-tailed tests
[a] Number of simulations in resampling=0
[b] Number of simulations in resampling=10,000

Figure 1. Time Trend of Frequency of Pirate Attacks and Mean Harm, 1994 to 2017.

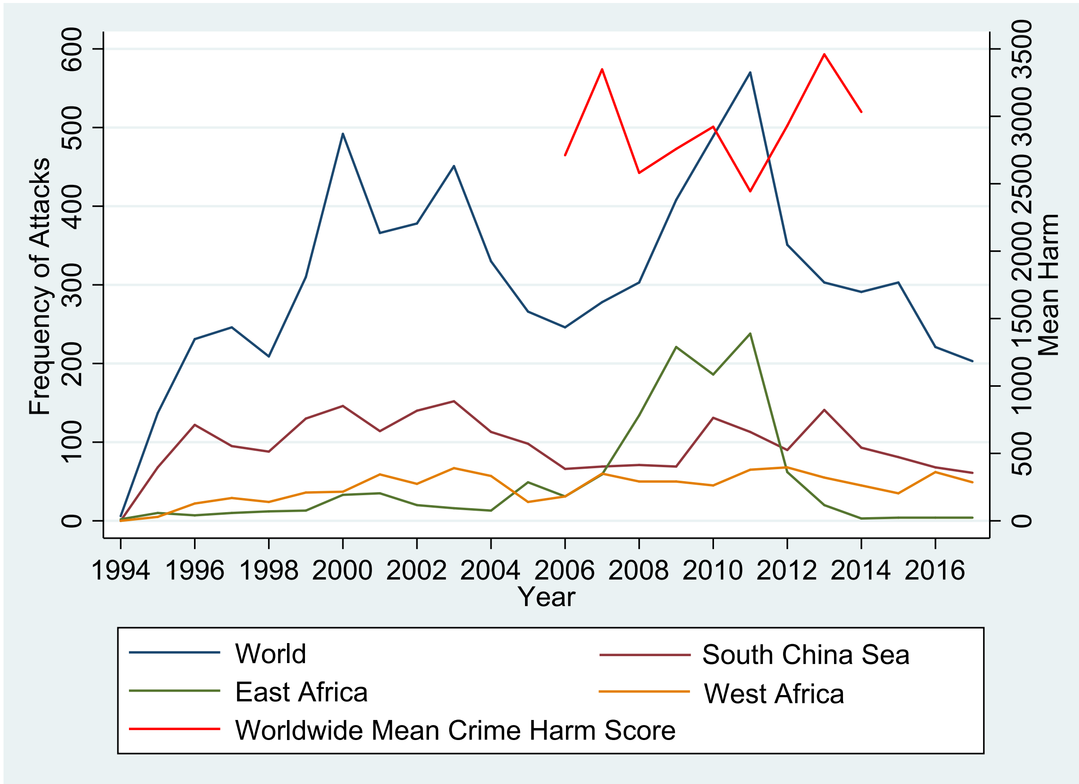


Figure 2A. Optimized Hot Spot Analysis of Frequency of Piracy Attacks Worldwide, 2006 to 2014

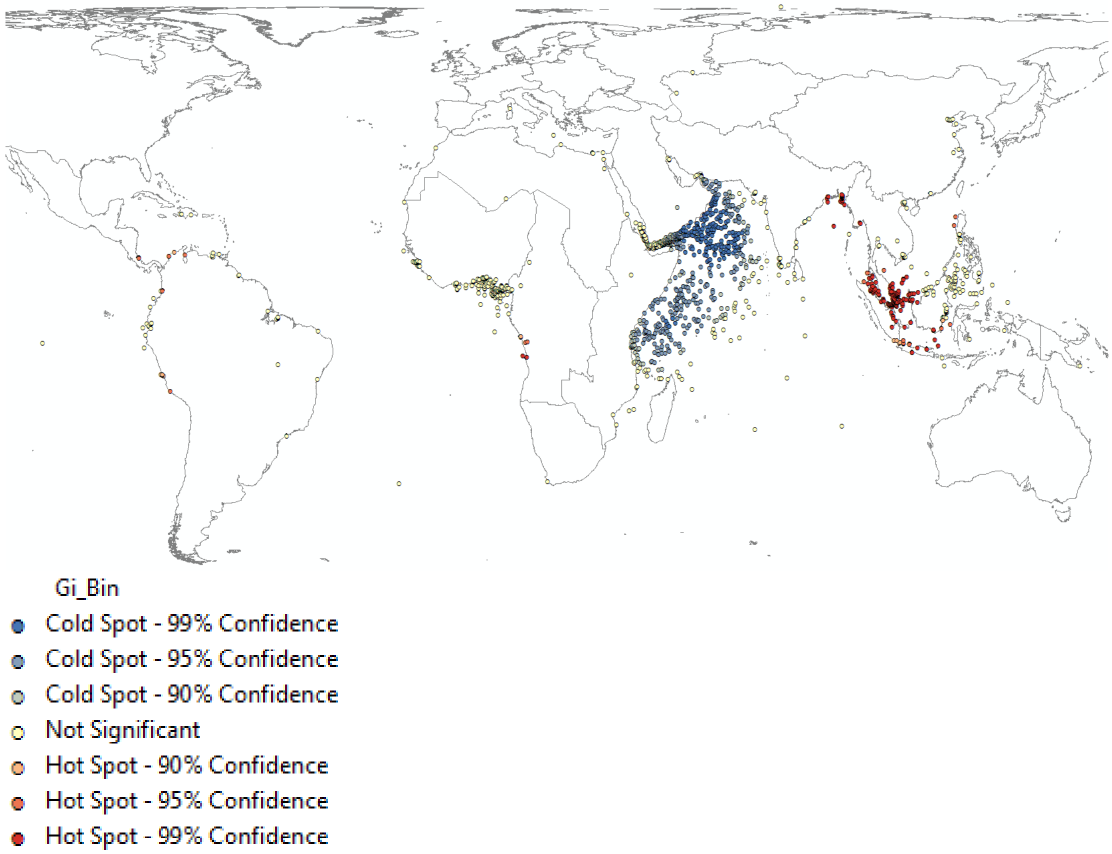


Figure 2B. Interpolation by Inverse Probability Weighting of Frequency of Piracy Attacks Worldwide, 2006 to 2014

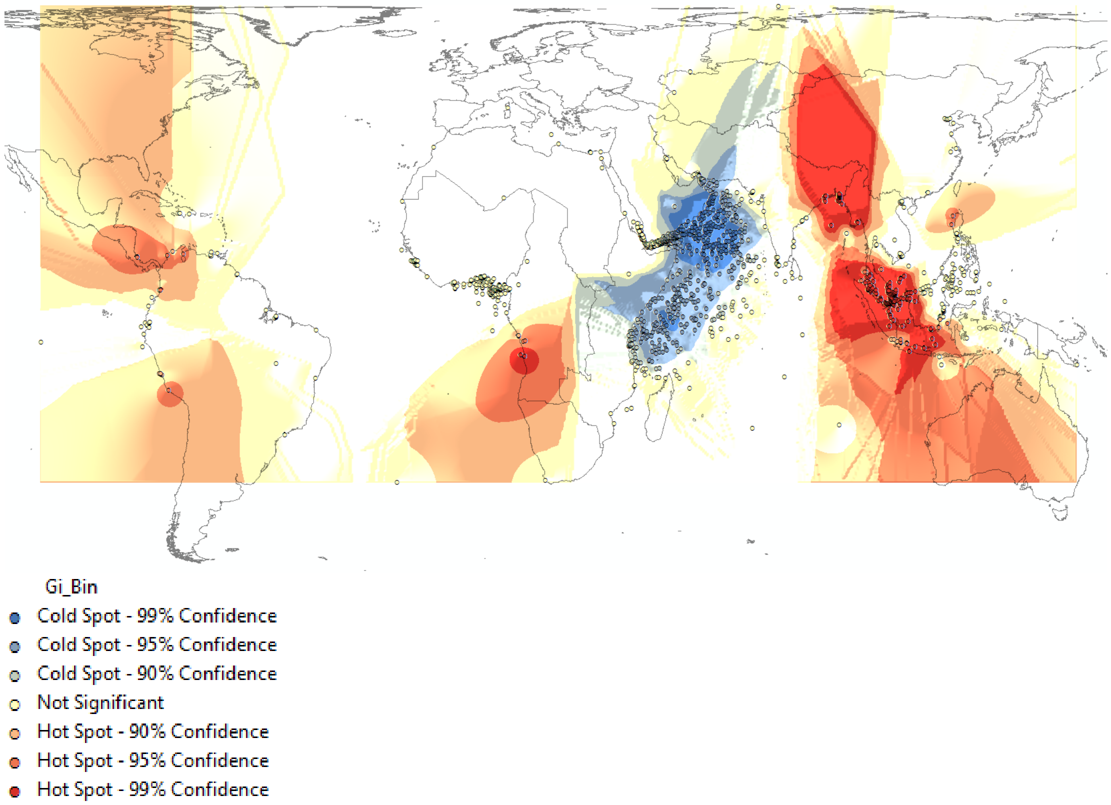


Figure 2C. Emerging Hot Spot Analysis of Frequency of Piracy Attacks Worldwide, 2006 to 2014

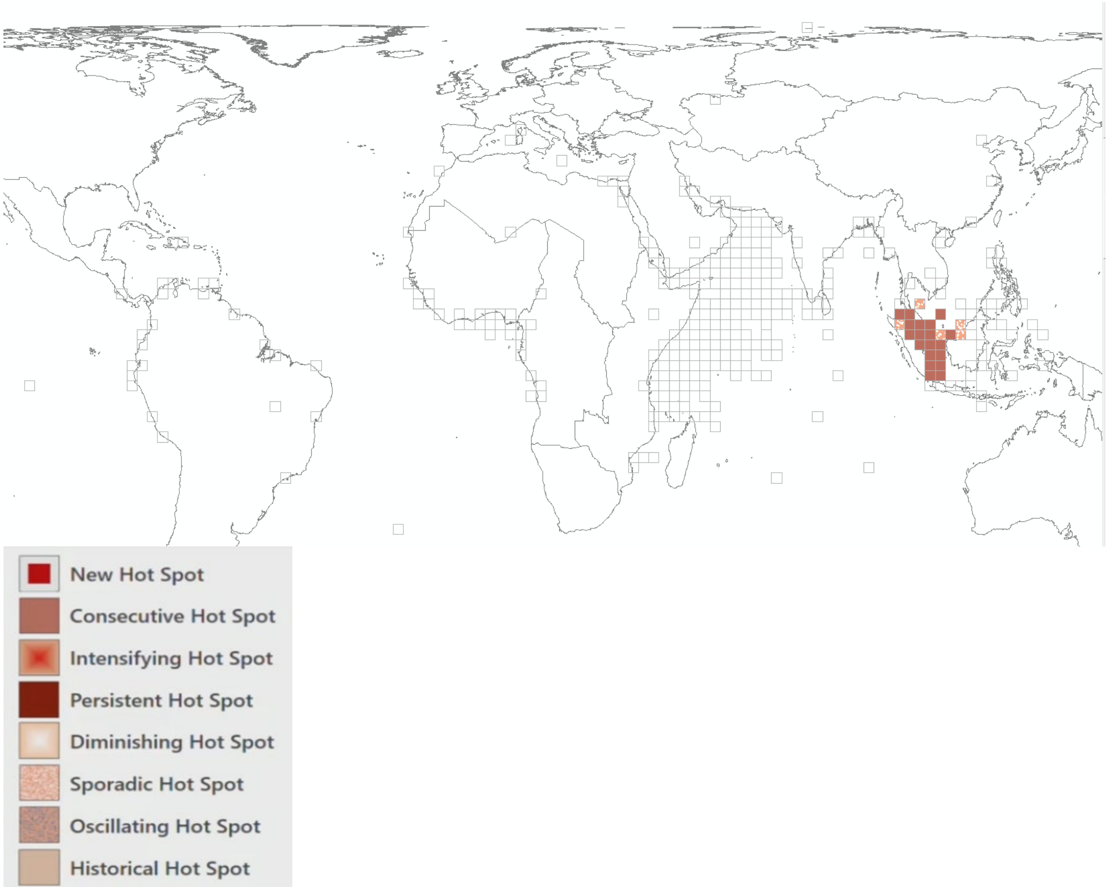


Figure 2D. Local Outlier Analysis of Frequency of Piracy Attacks Worldwide, 2006 to 2014

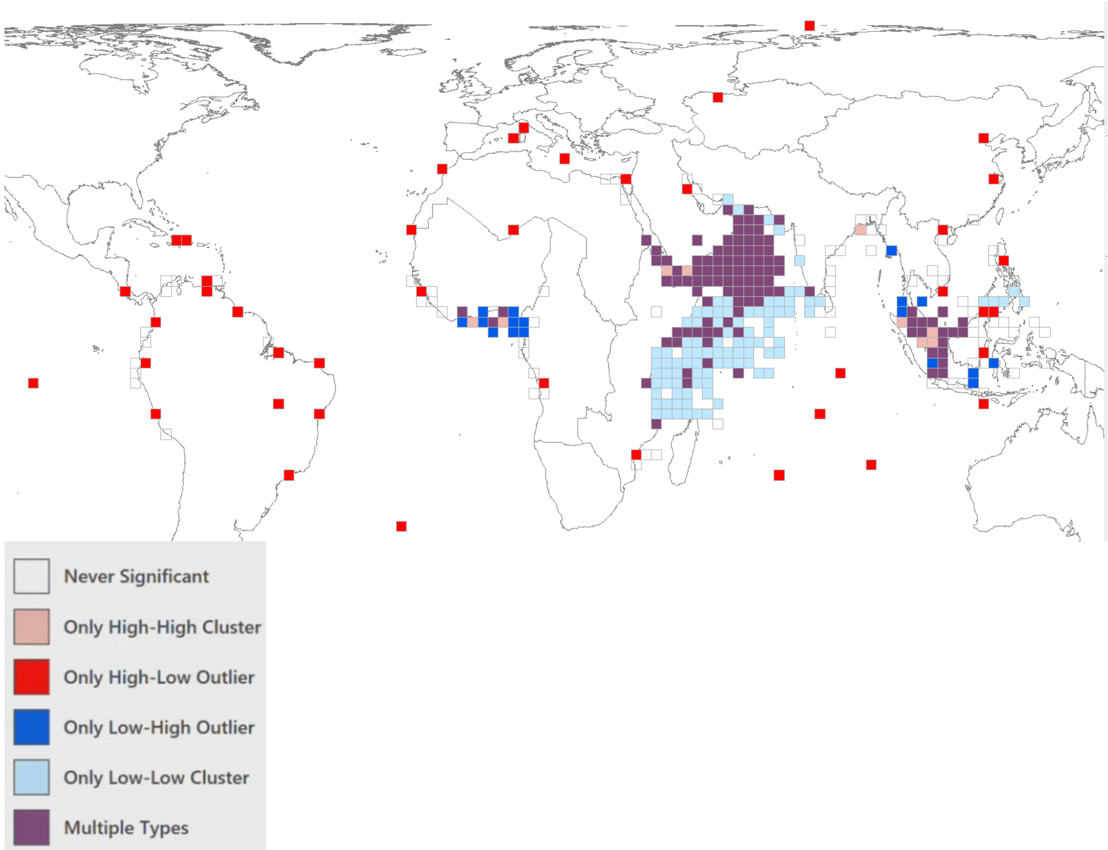


Figure 3A. Optimized Hot Spot Analysis of Harm of Piracy Attacks Worldwide, 2006 to 2014

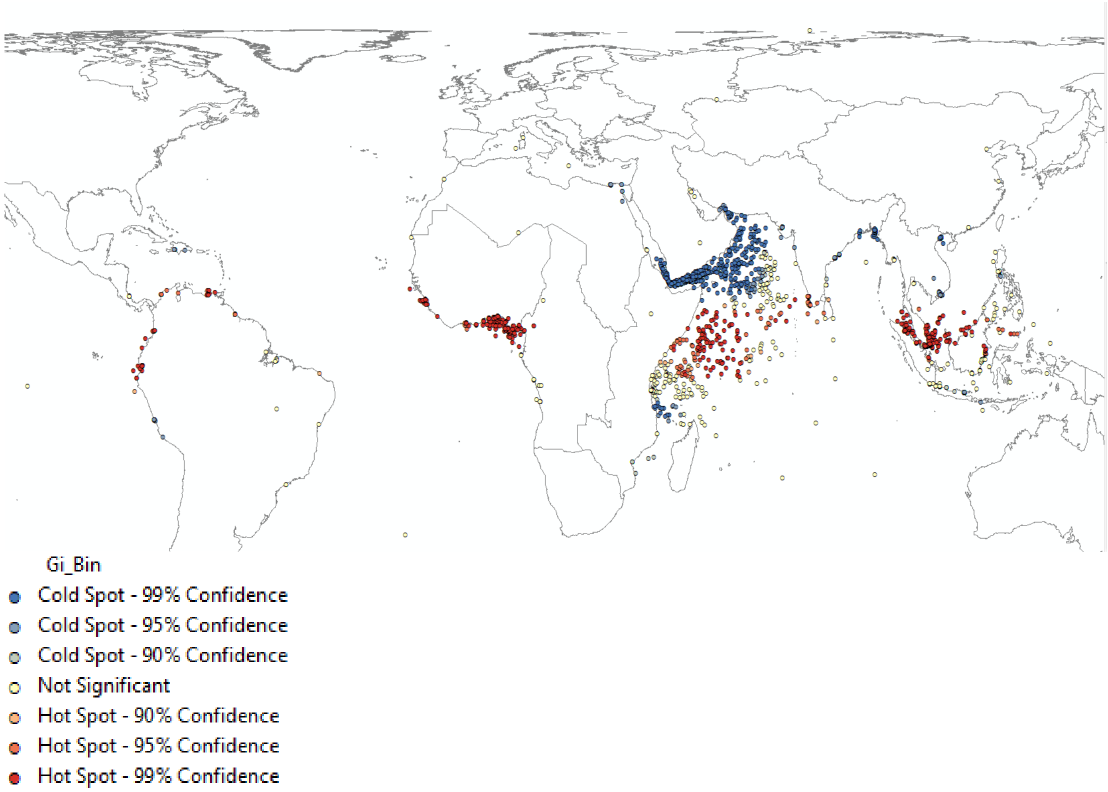


Figure 3B. Interpolation by Inverse Distance Weighting of Harm of Piracy Attacks Worldwide, 2006 to 2014

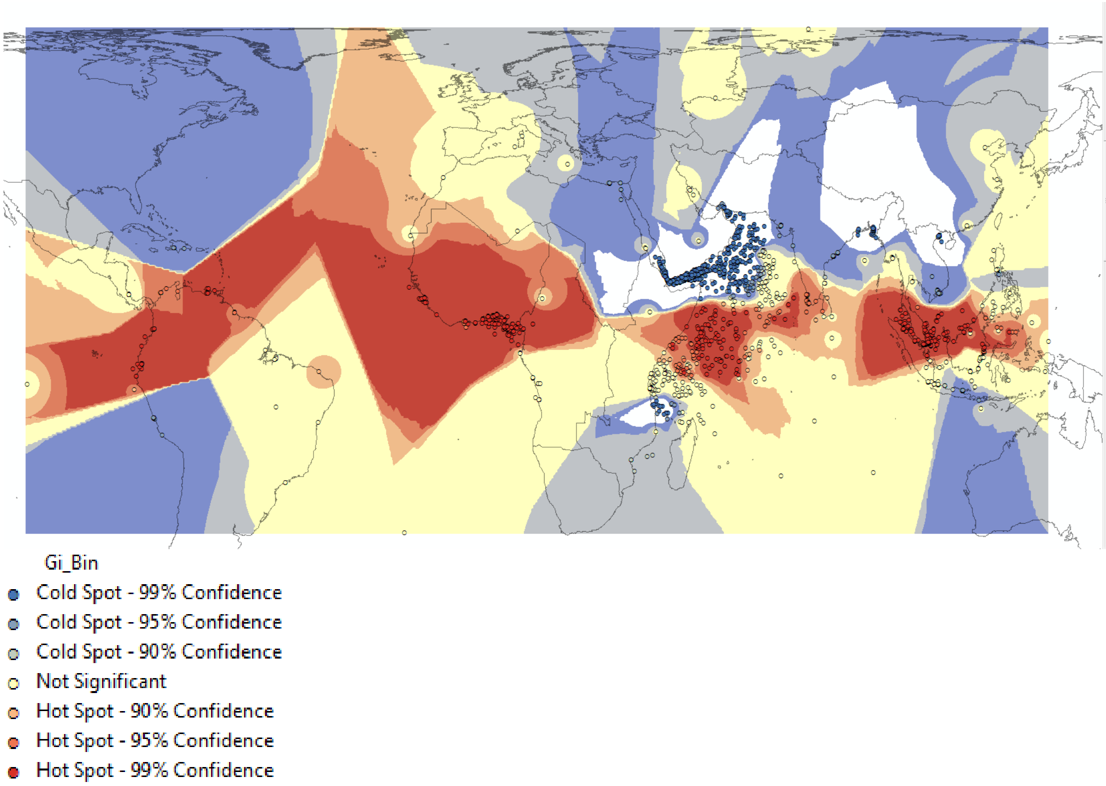


Figure 3C. Emerging Hot Spot Analysis of Harm of Piracy Attacks Worldwide, 2006 to 2014

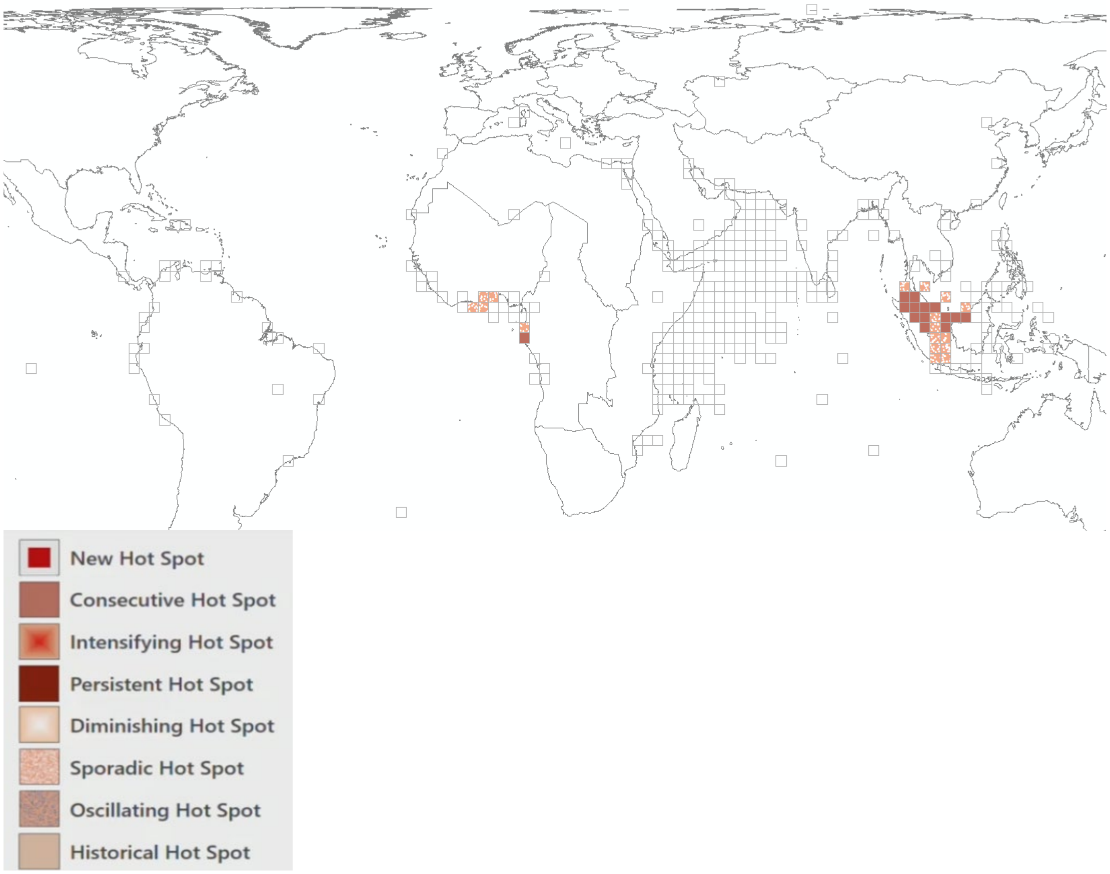


Figure 3D. Local Outlier Analysis of Harm of Piracy Attacks Worldwide, 2006 to 2014

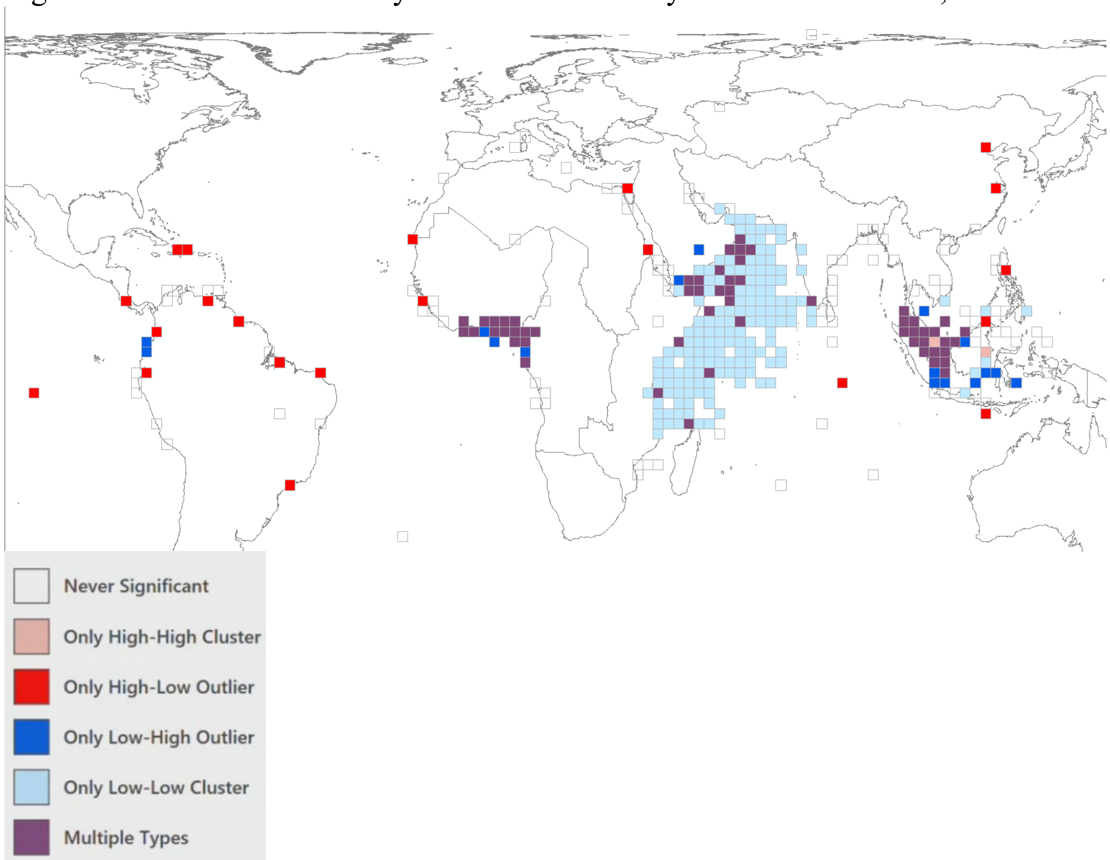
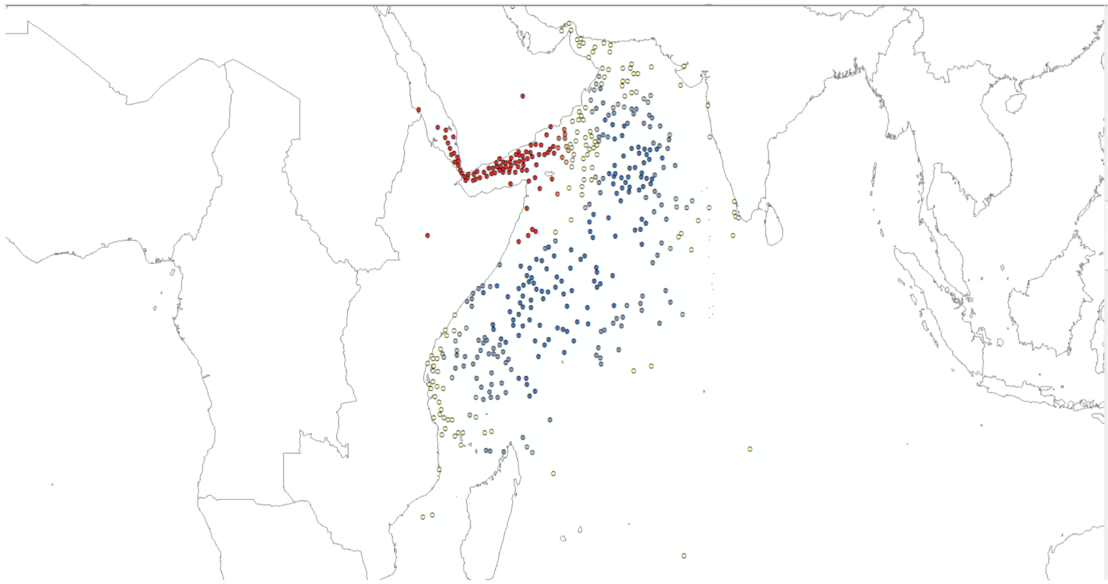


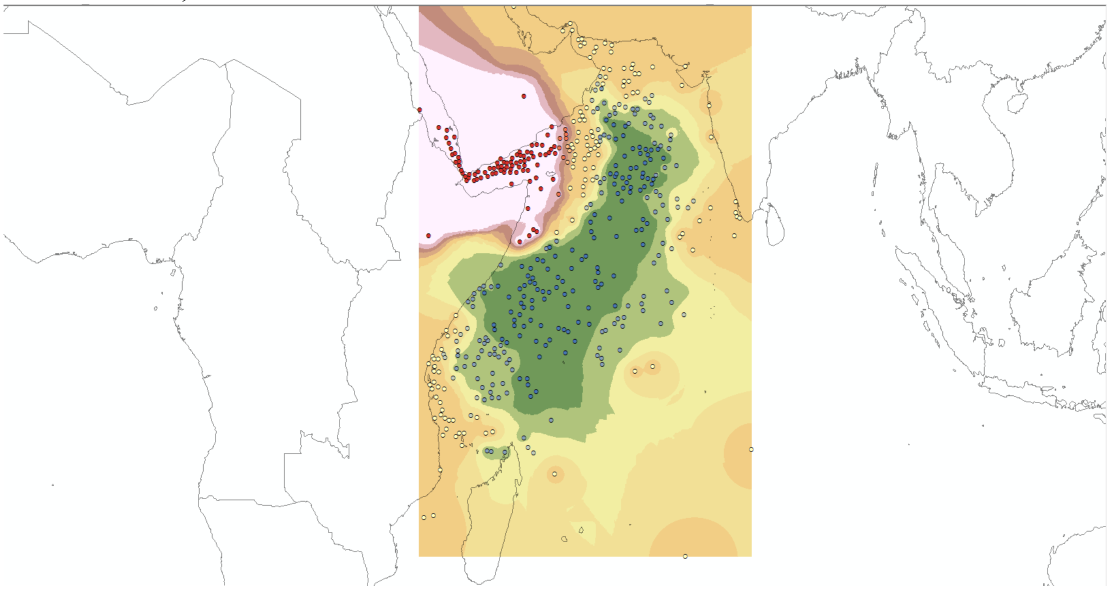
Figure 4A. Optimized Hot Spot Analysis of Frequency of Piracy Attacks in East Africa, 2006 to 2014



Gi_Bin

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- Not Significant
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

Figure 4B. Interpolation by Inverse Distance Weighting of Frequency of Piracy Attacks in East Africa, 2006 to 2014



Gi_Bin

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- Not Significant
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

Figure 4C. Emerging Hot Spot Analysis of Frequency of Piracy Attacks in East Africa, 2006 to 2014

Figure 4D. Local Outlier Analysis of Frequency of Piracy Attacks in East Africa, 2006 to 2014

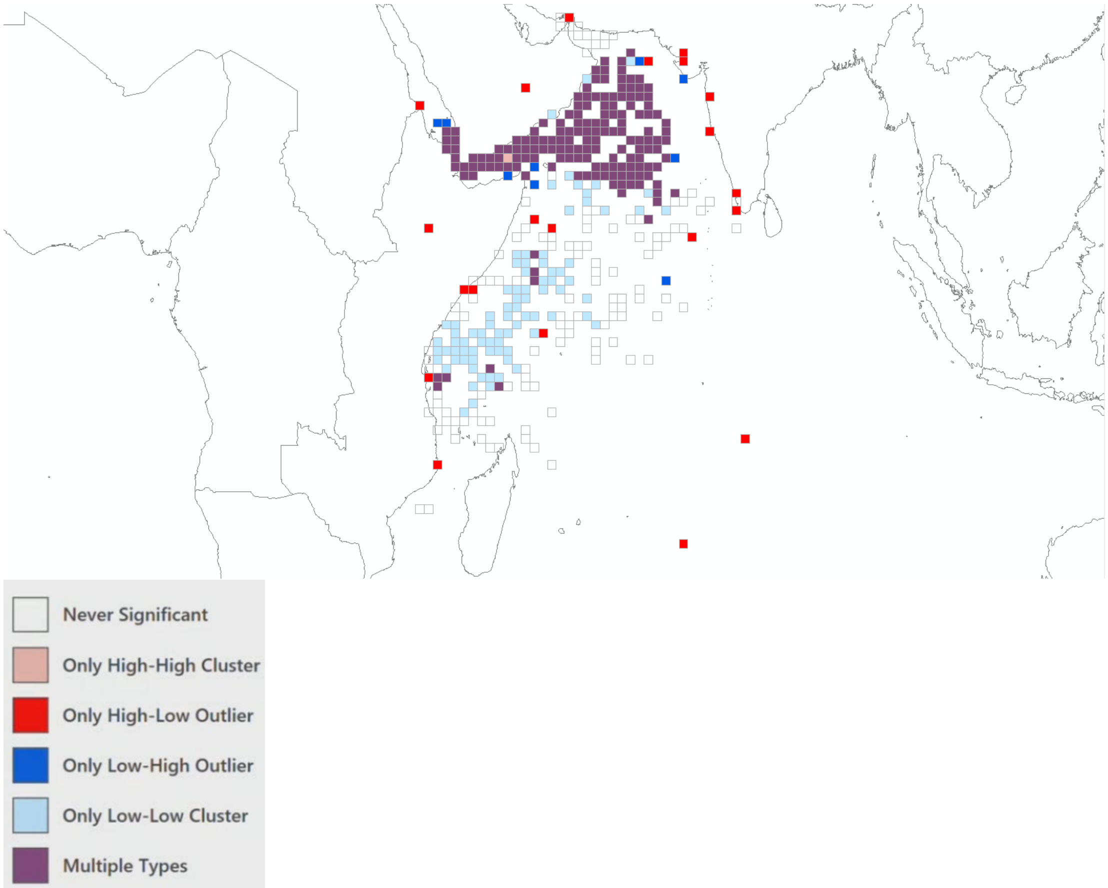


Figure 5A. Optimized Hot Spot Analysis of Harm of Piracy Attacks in East Africa, 2006 to 2014

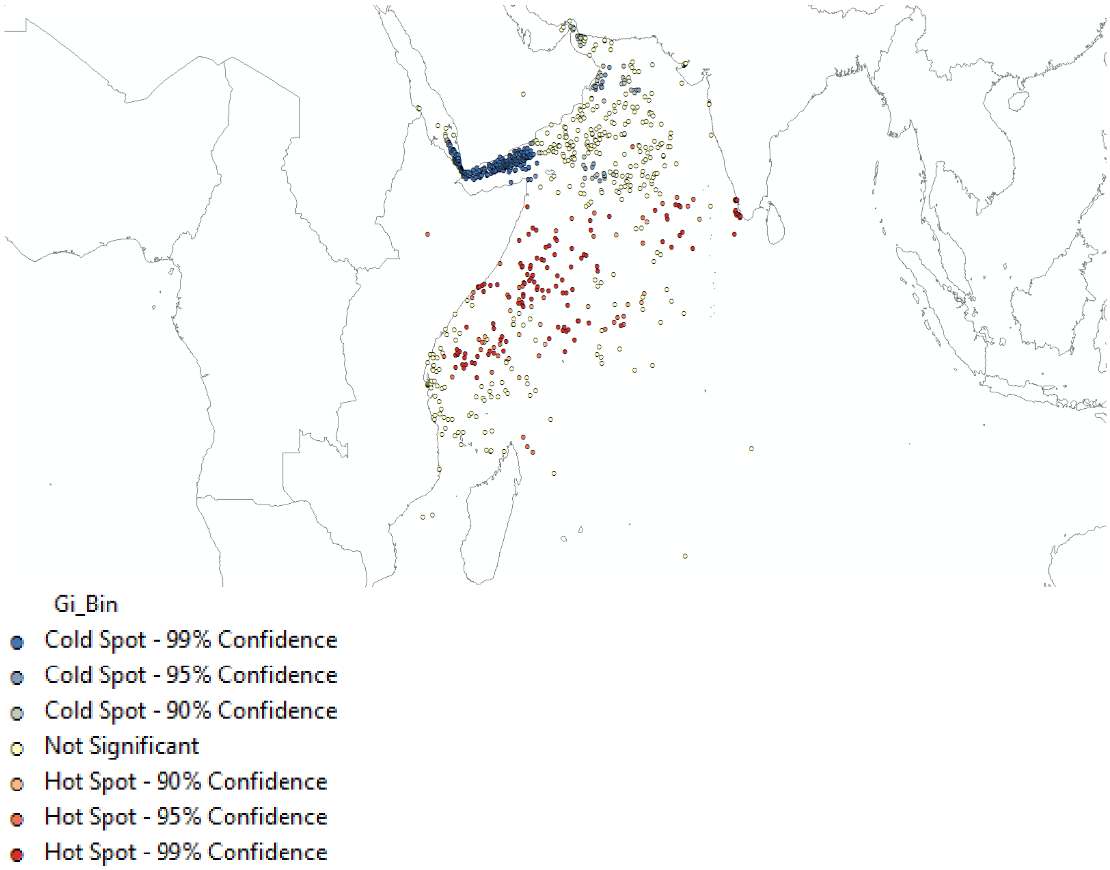


Figure 5B. Interpolation by Inverse Probability Weighting of Harm of Piracy Attacks in East Africa, 2006 to 2014

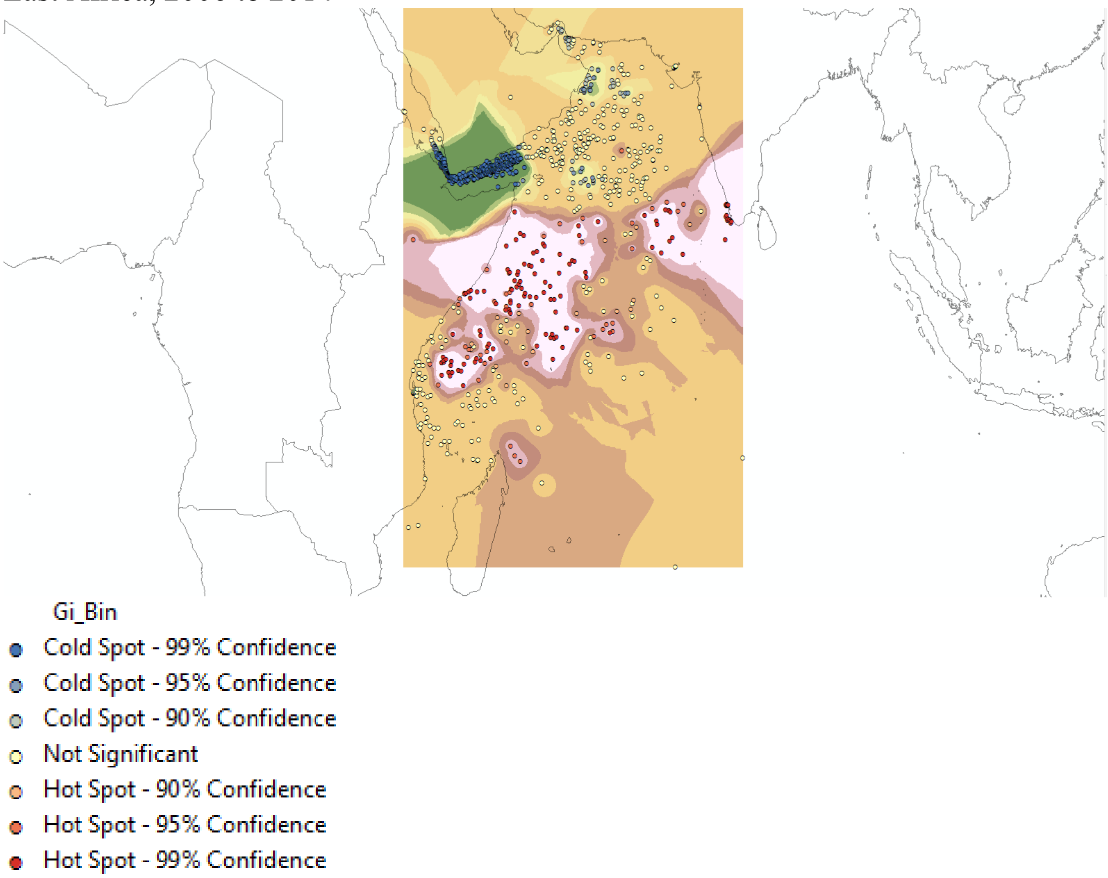


Figure 5C. Emerging Hot Spot Analysis of Harm of Piracy Attacks in East Africa, 2006 to 2014

Figure 5D. Local Outlier Analysis of Harm of Piracy Attacks in East Africa, 2006 to 2014

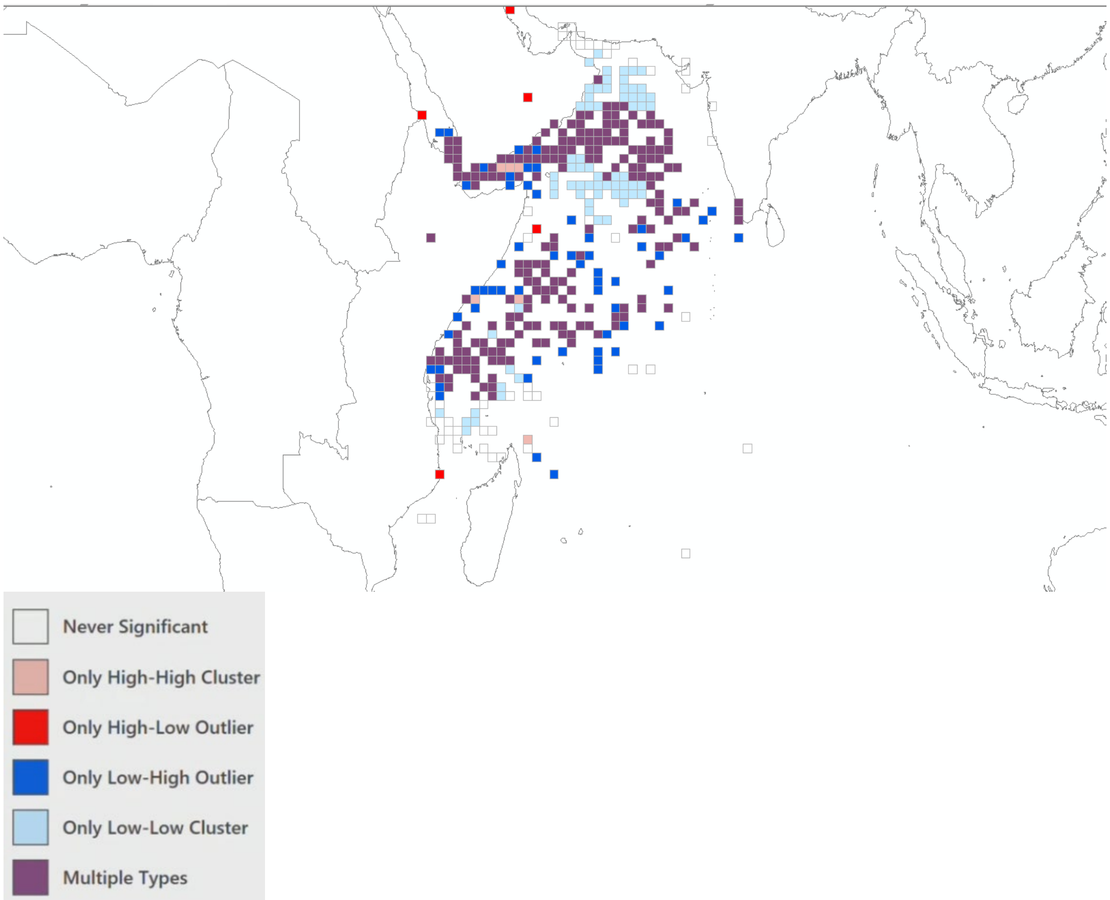


Figure 6A. Optimized Hot Spot Analysis of Frequency of Piracy Attacks in Malacca Strait and South China Sea, 2006 to 2014

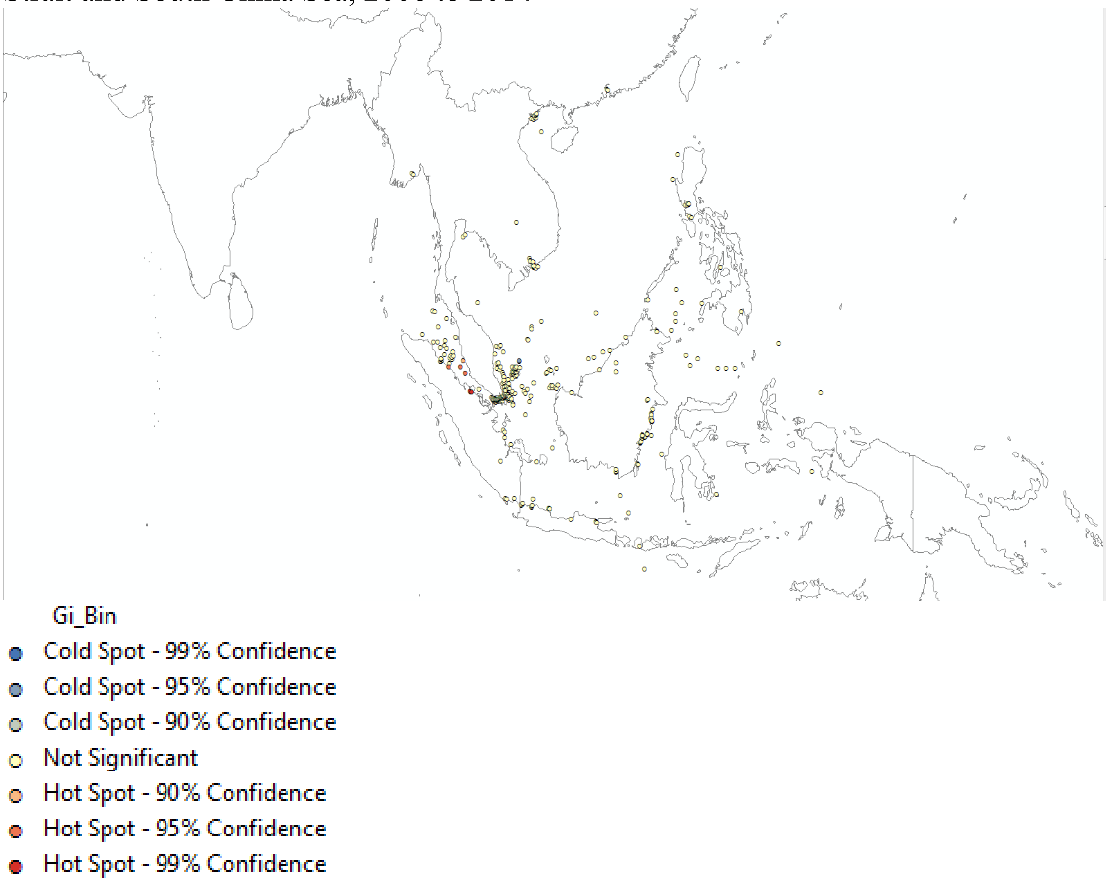


Figure 6B. Interpolation by Inverse Probability Weighting of Frequency of Piracy Attacks in Malacca Strait and South China Sea, 2006 to 2014

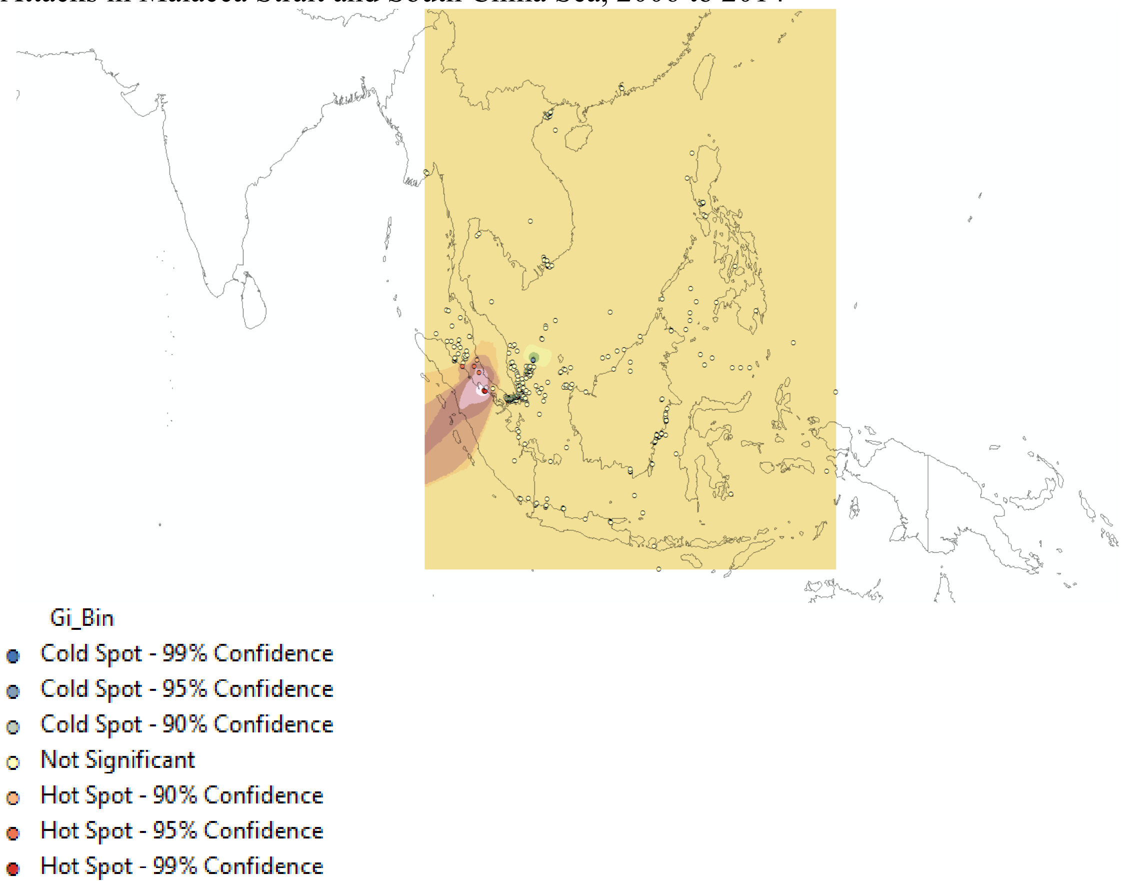


Figure 6C. Emerging Hot Spot Analysis of Frequency of Piracy Attacks in Malacca Strait and South China Sea, 2006 to 2014

Figure 6D. Local Outlier Analysis of Frequency of Piracy Attacks in Malacca Strait and South China Sea, 2006 to 2014

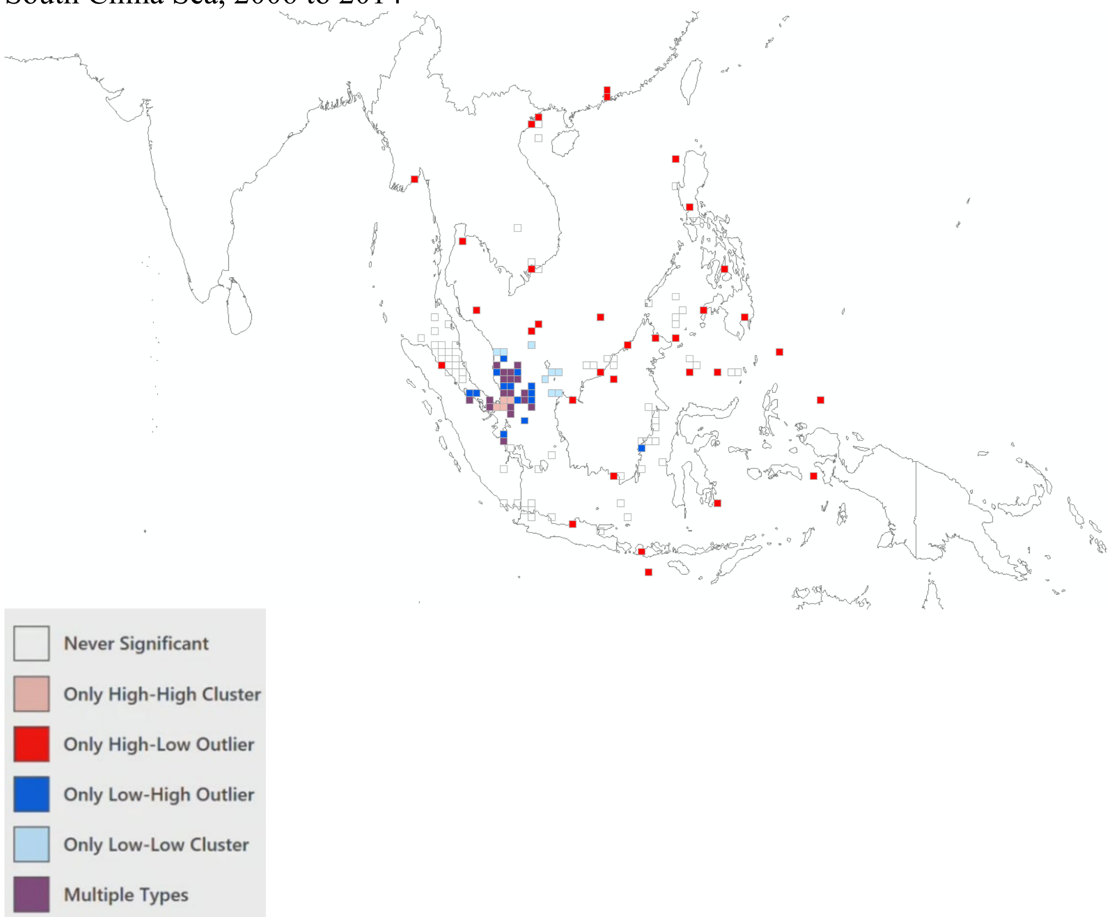


Figure 7A. Optimized Hot Spot Analysis of Harm of Piracy Attacks in Malacca Strait and South China Sea, 2006 to 2014

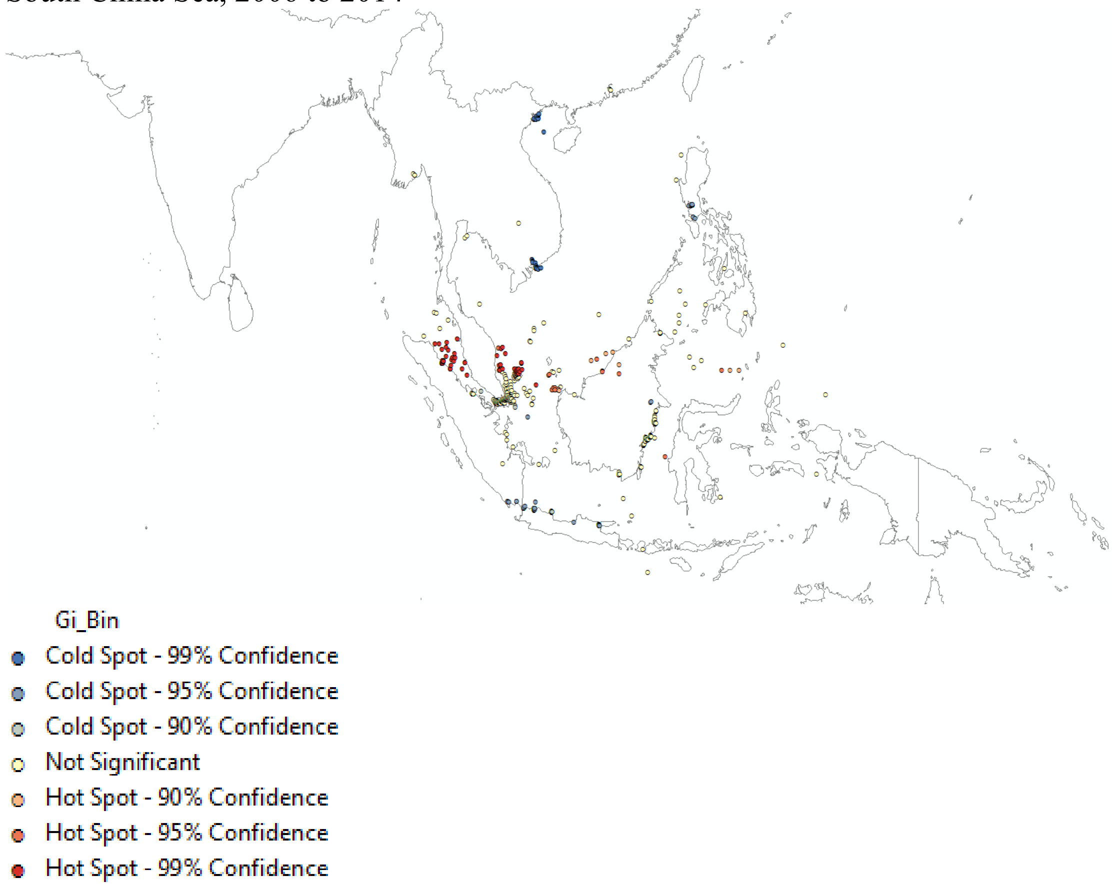
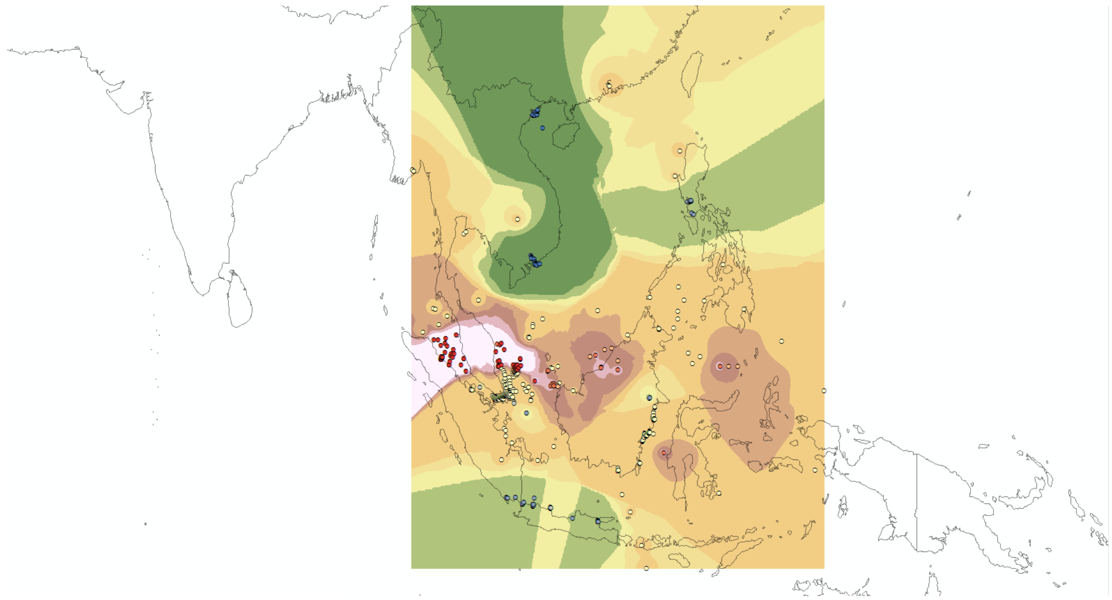


Figure 7B. Interpolation by Inverse Probability Weighting of Harm of Piracy Attacks in Malacca Strait and South China Sea, 2006 to 2014



Gi_Bin
- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- Not Significant
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

Figure 7C. Emerging Hot Spot Analysis of Harm of Piracy Attacks in Malacca Strait and South China Sea, 2006 to 2014

Figure 7D. Local Outlier Analysis of Harm of Piracy Attacks in Malacca Strait and South China Sea, 2006 to 2014

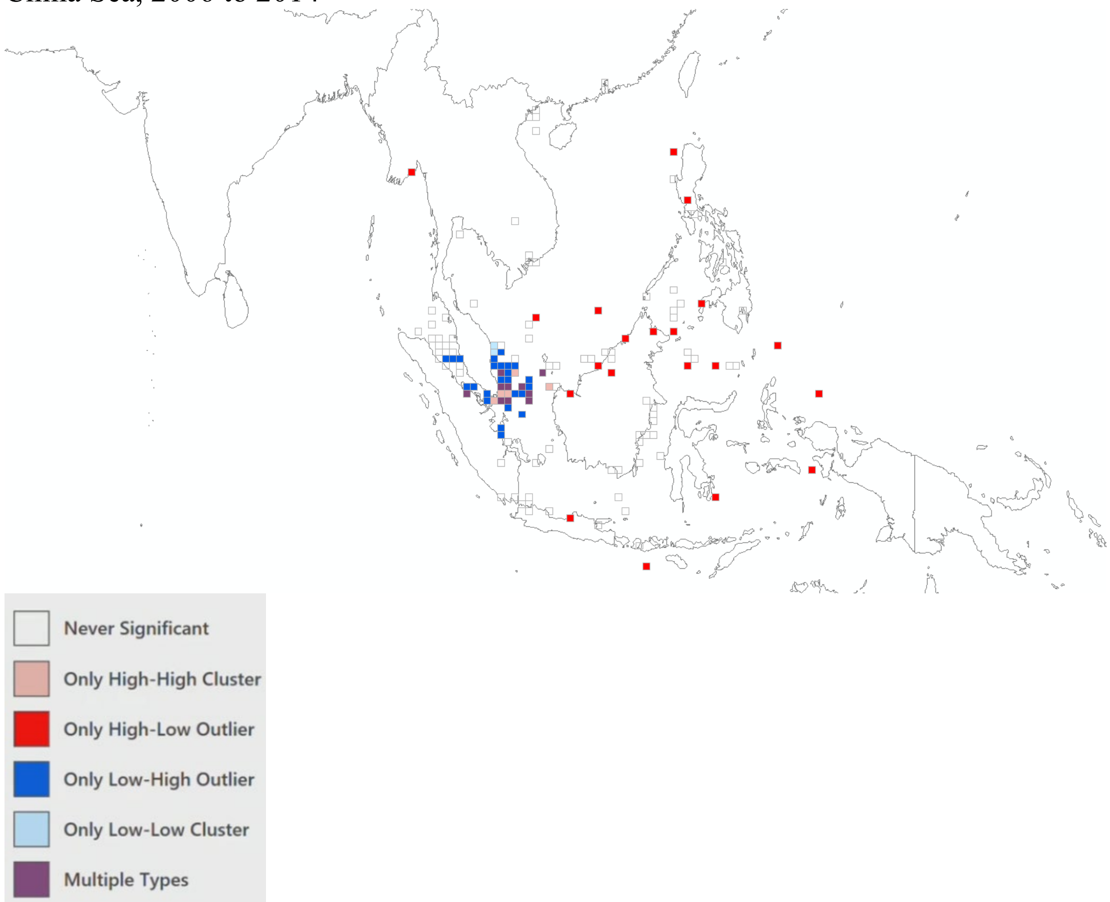


Figure 8A. Concentration of Frequency at the Grid Level, Piracy Attacks Worldwide, 2006 to 2014

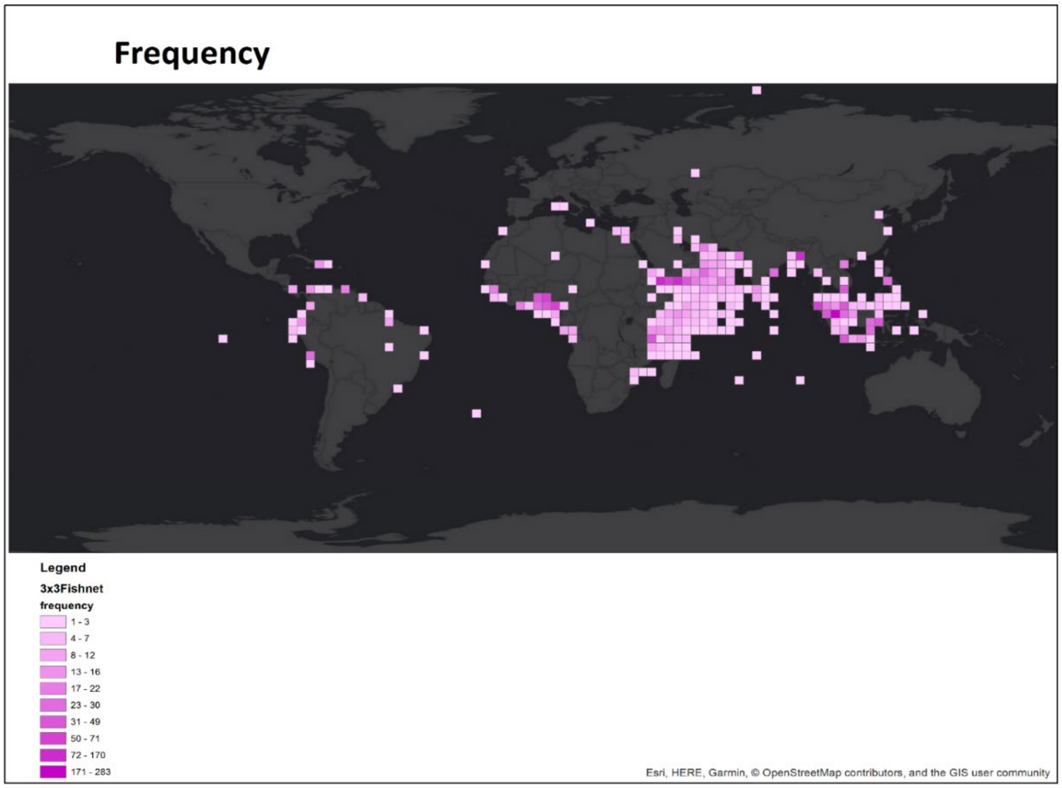


Figure 8B. Concentration of Harm at the Grid Level, Piracy Attacks Worldwide, 2006 to 2014

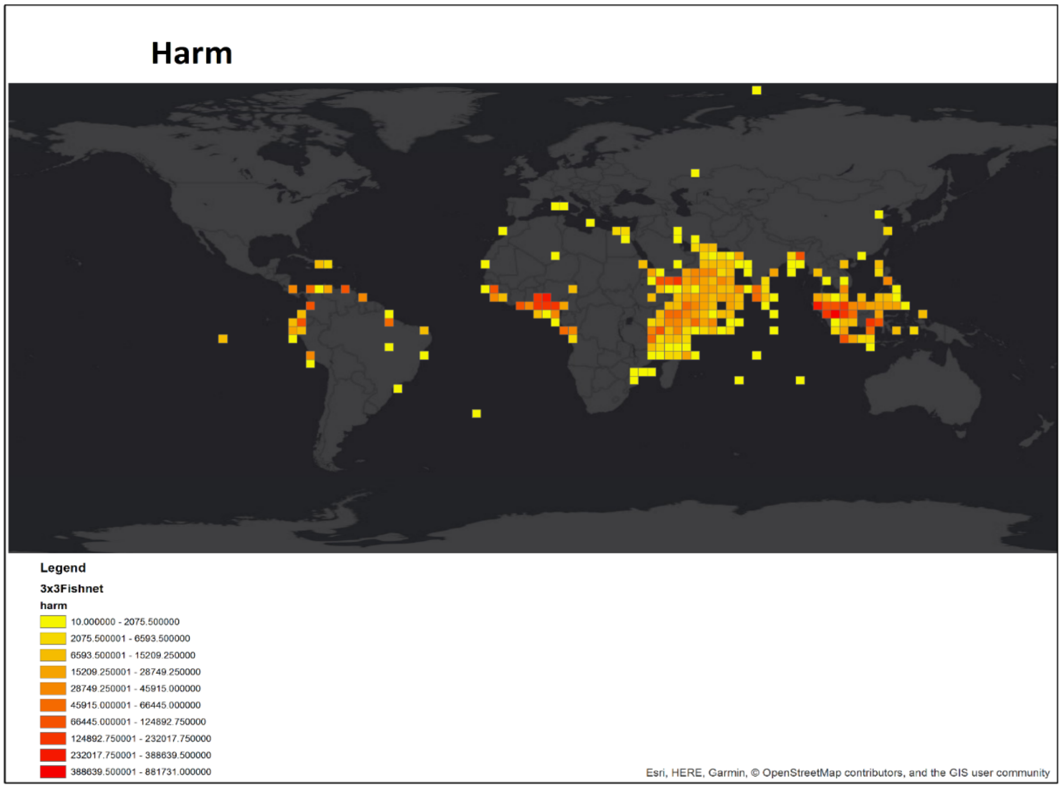


Figure 8C. Overlapping Grids of Frequency and Harm, Piracy Attacks Worldwide, 2006 to 2014

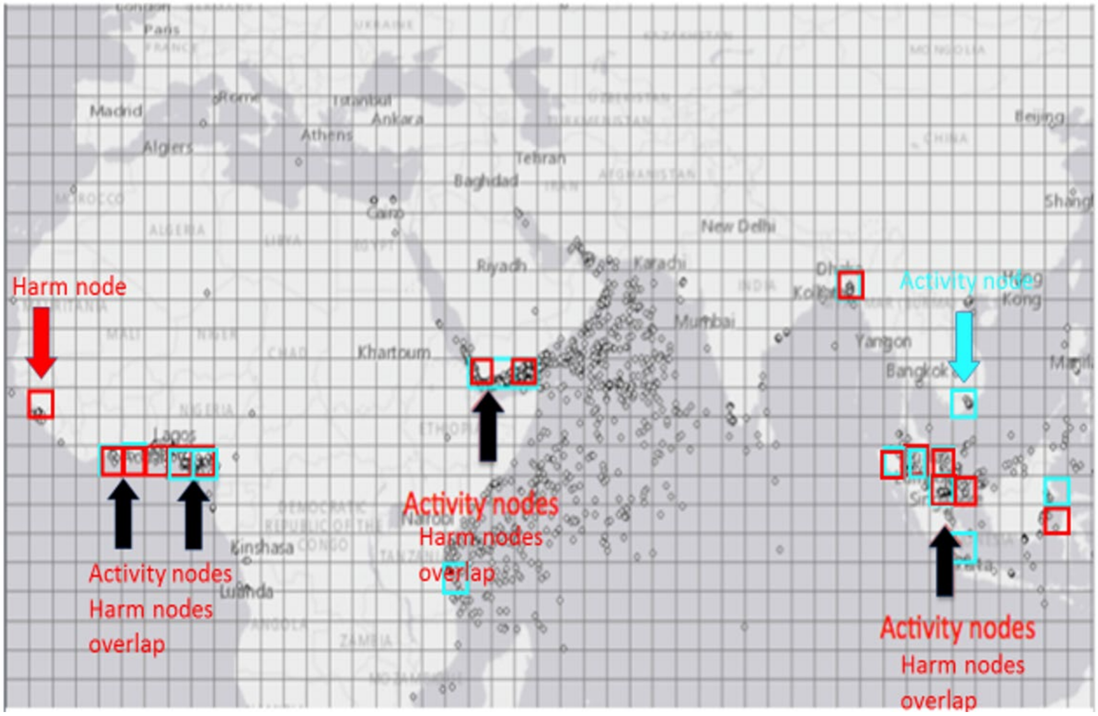


Figure 8D-1. 3D Visualization of Hot Spots/Harm Spots and Co-Locations, Piracy Attacks Worldwide, 2006 to 2014

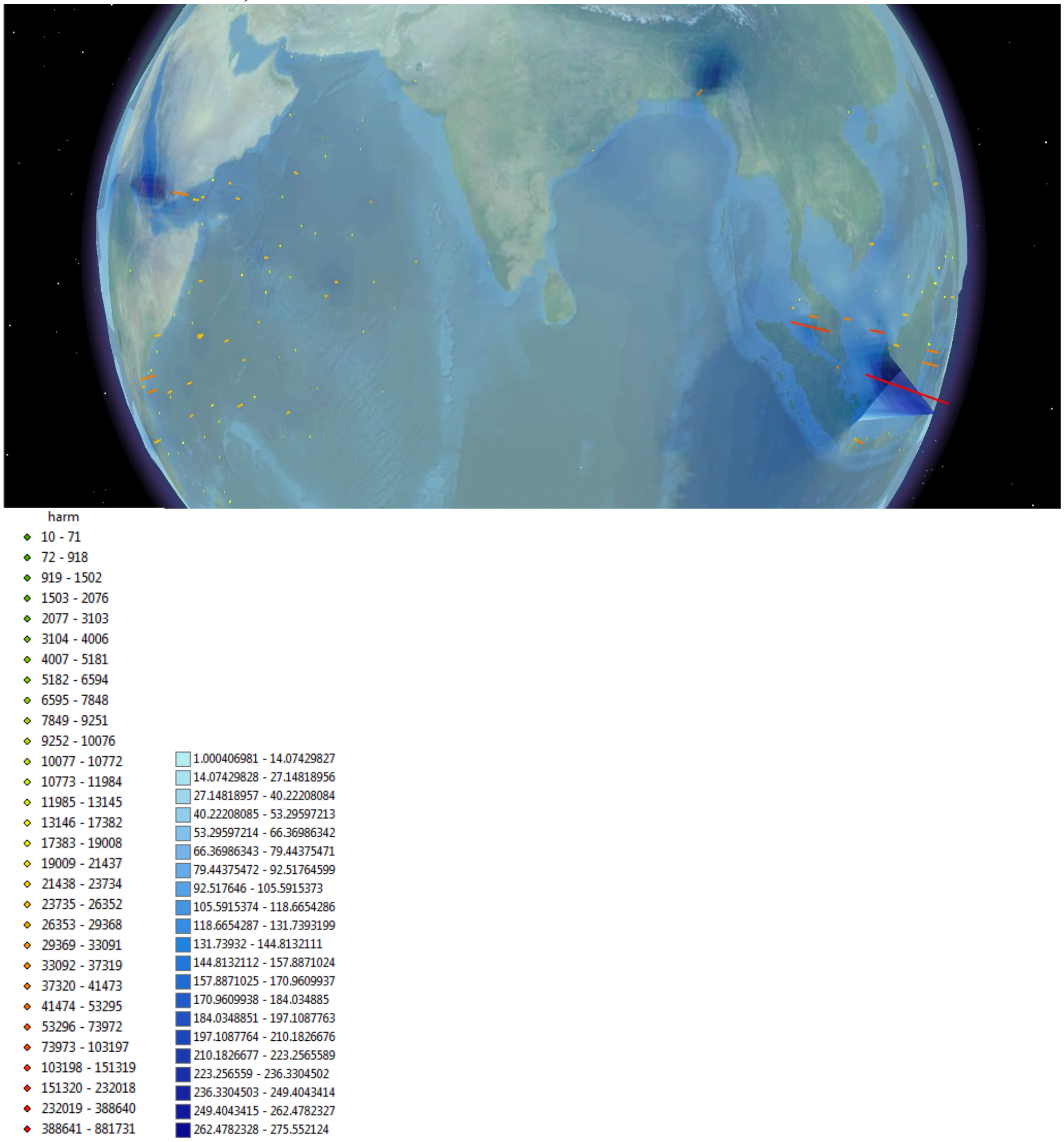


Figure 8D-2. 3D Visualization of Hot Spots/Harm Spots and Co-Locations, Piracy Attacks Worldwide, 2006 to 2014

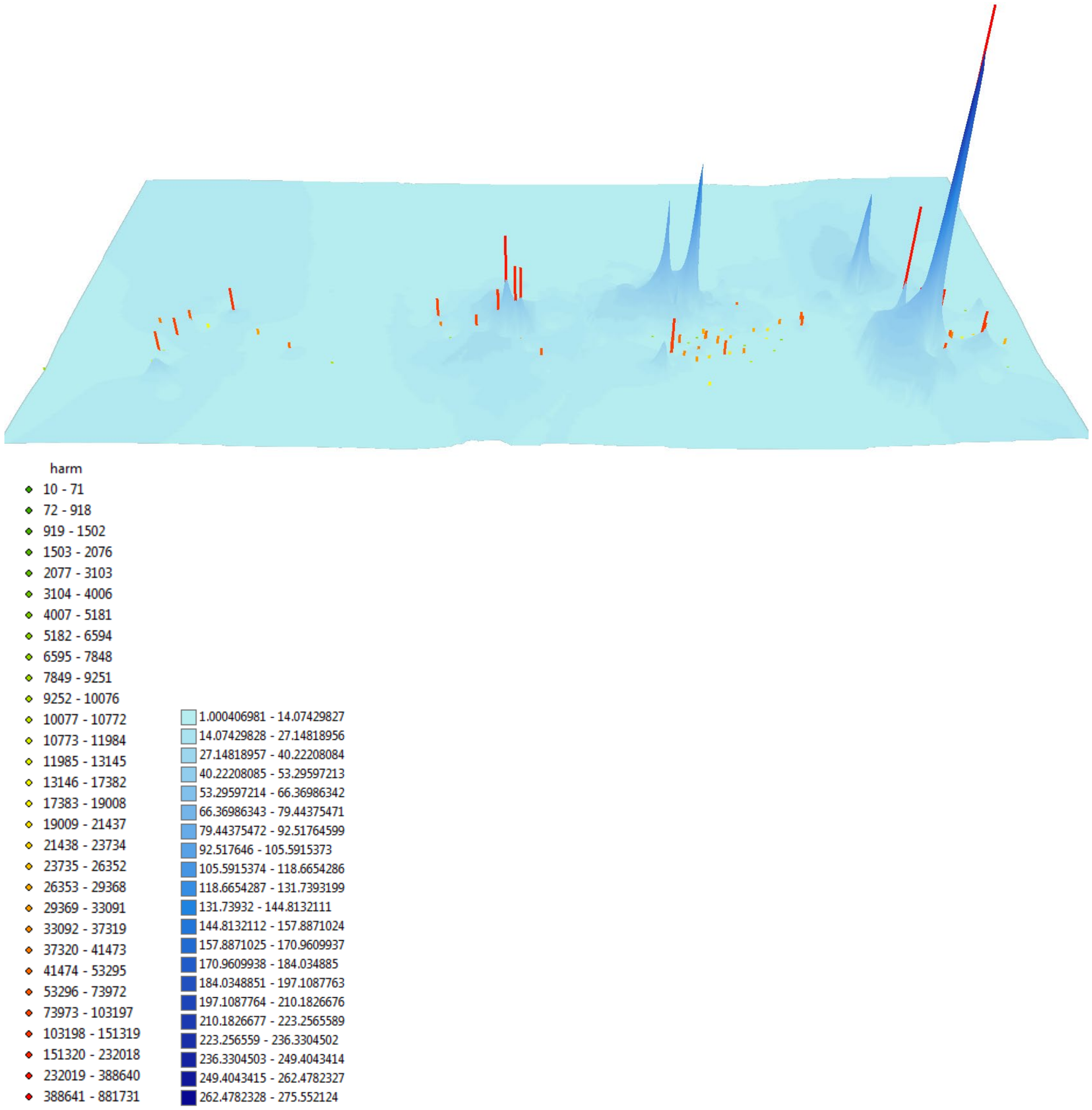


Figure 8D-3. 3D Visualization of Hot Spots/Harm Spots and Co-Locations, Piracy Attacks Worldwide, 2006 to 2014

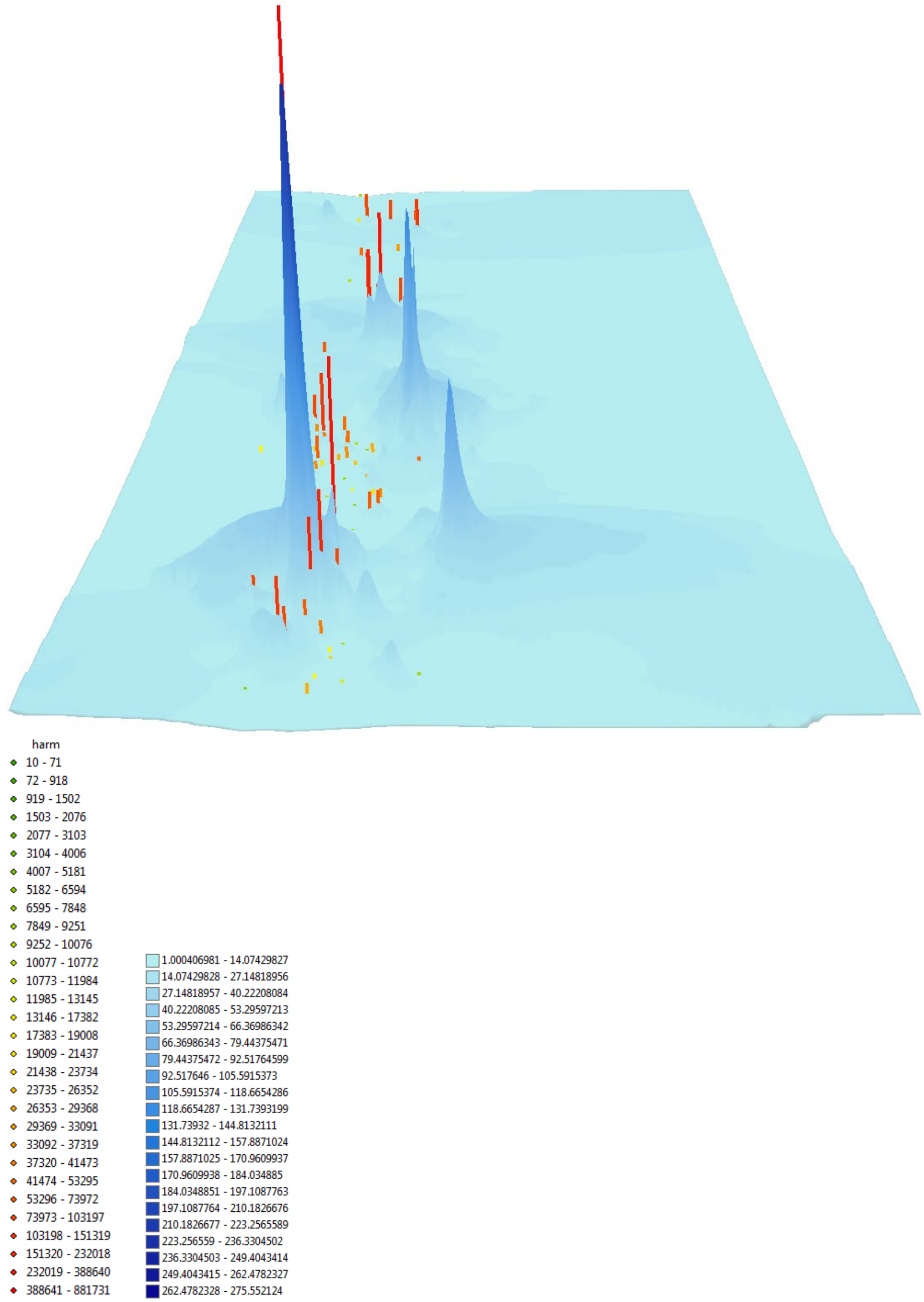


Figure 8D-4. 3D Visualization of Hot Spots/Harm Spots and Co-Locations, Piracy Attacks Worldwide, 2006 to 2014

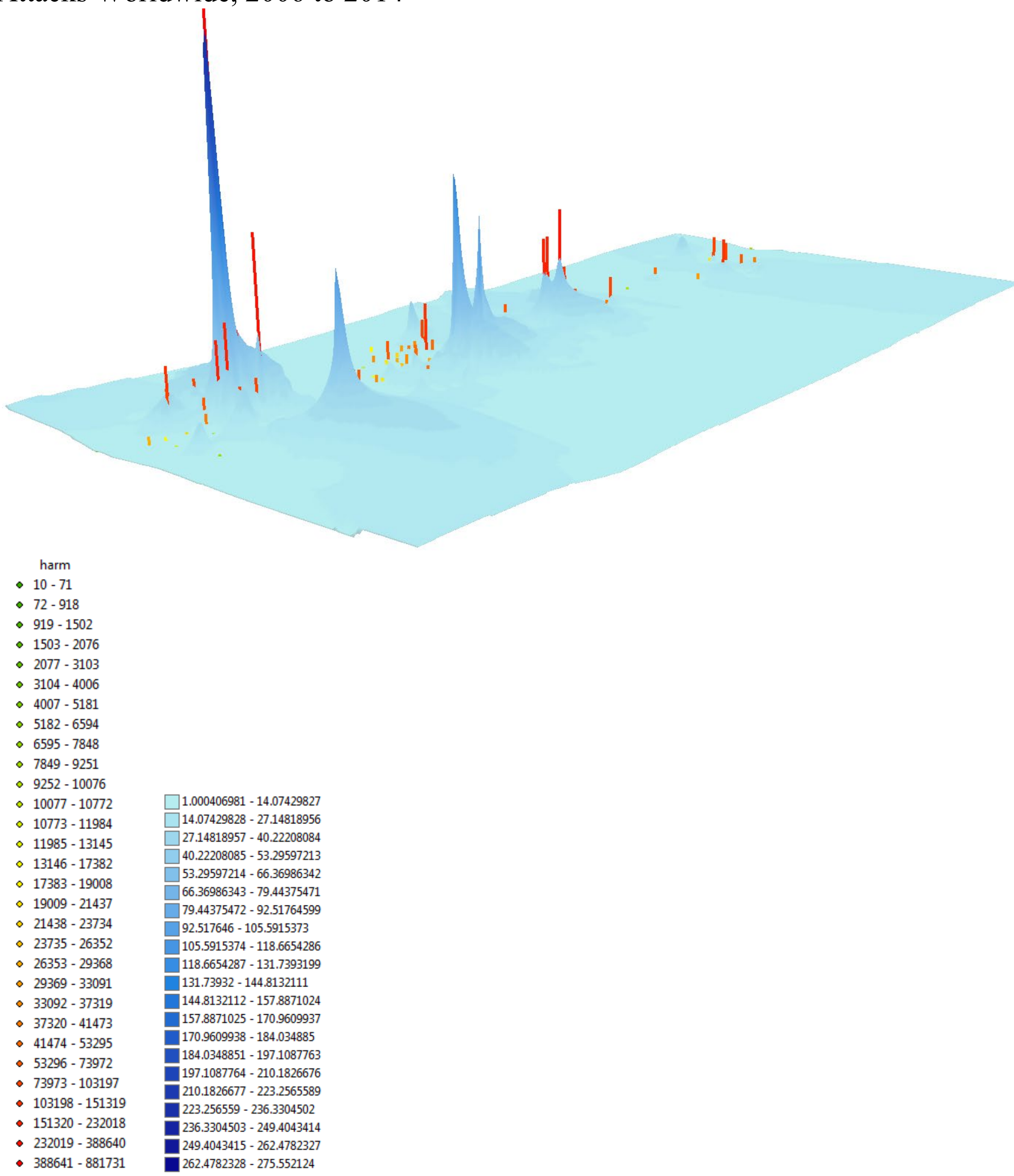


Figure 8D-5. 3D Visualization of Hot Spots/Harm Spots and Co-Locations, Piracy Attacks Worldwide, 2006 to 2014

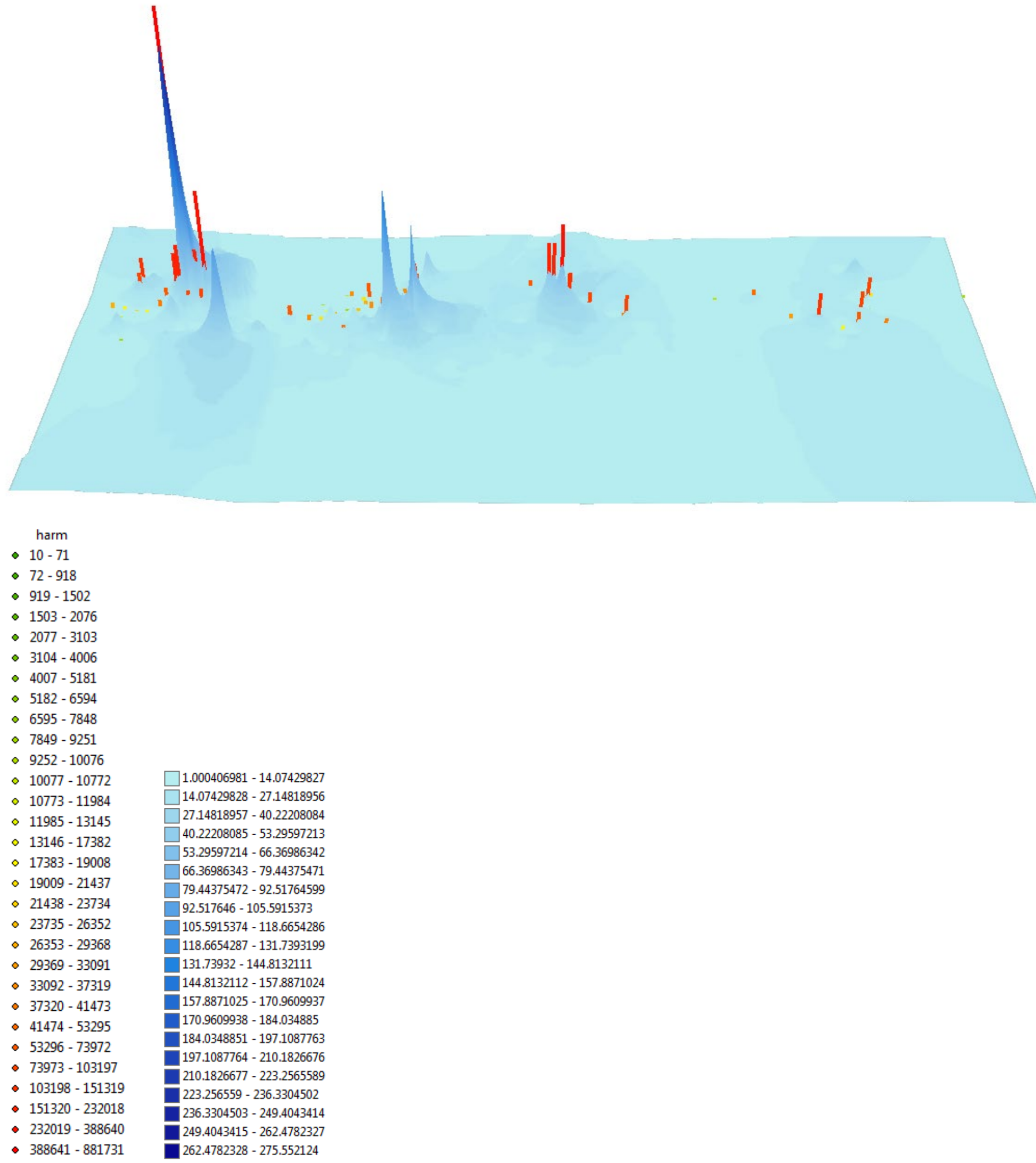


Figure 8D-6. 3D Visualization of Hot Spots/Harm Spots and Co-Locations, Piracy Attacks Worldwide, 2006 to 2014

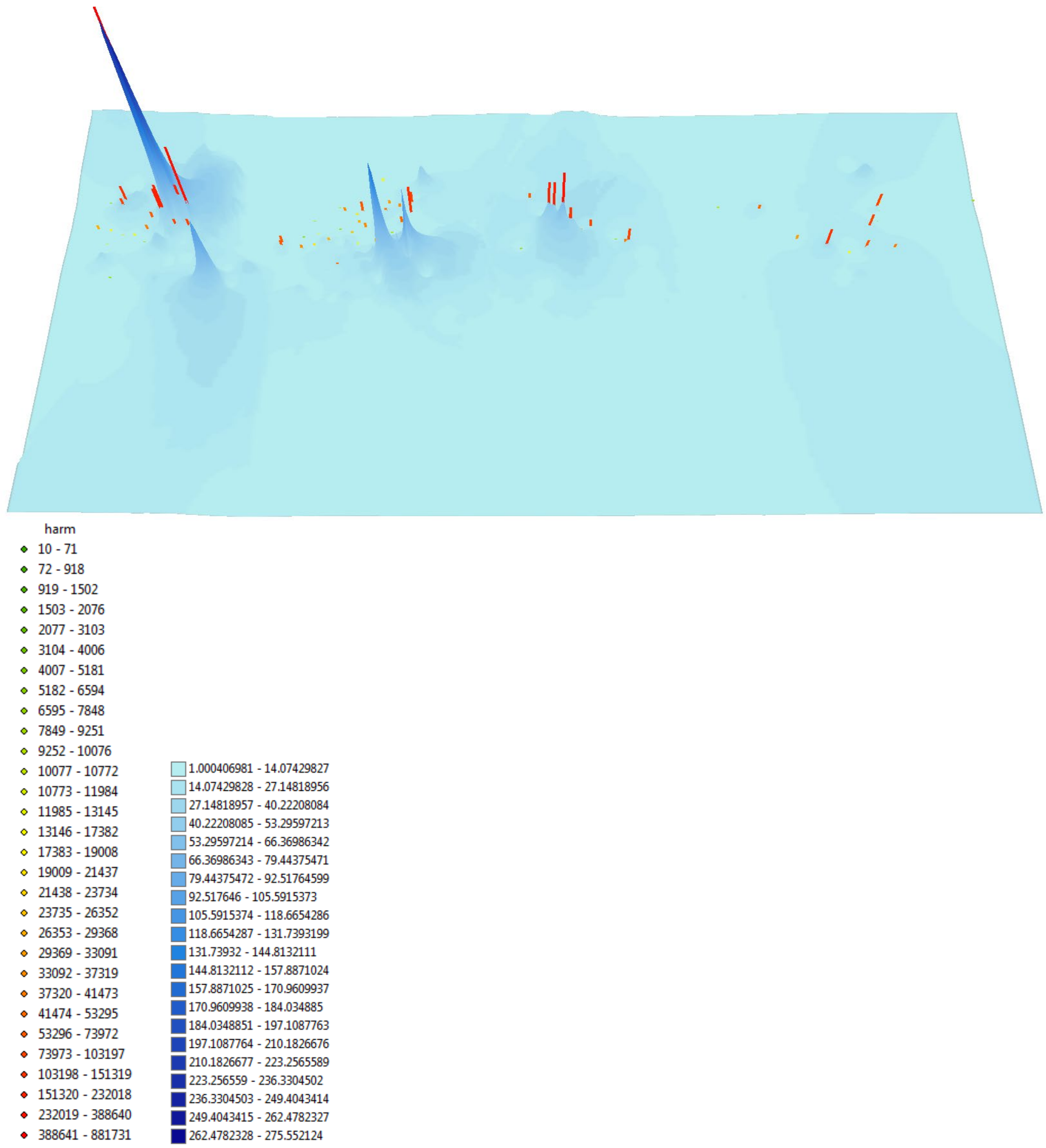


Figure 8D-7. 3D Visualization of Hot Spots/Harm Spots and Co-Locations, Piracy Attacks Worldwide, 2006 to 2014

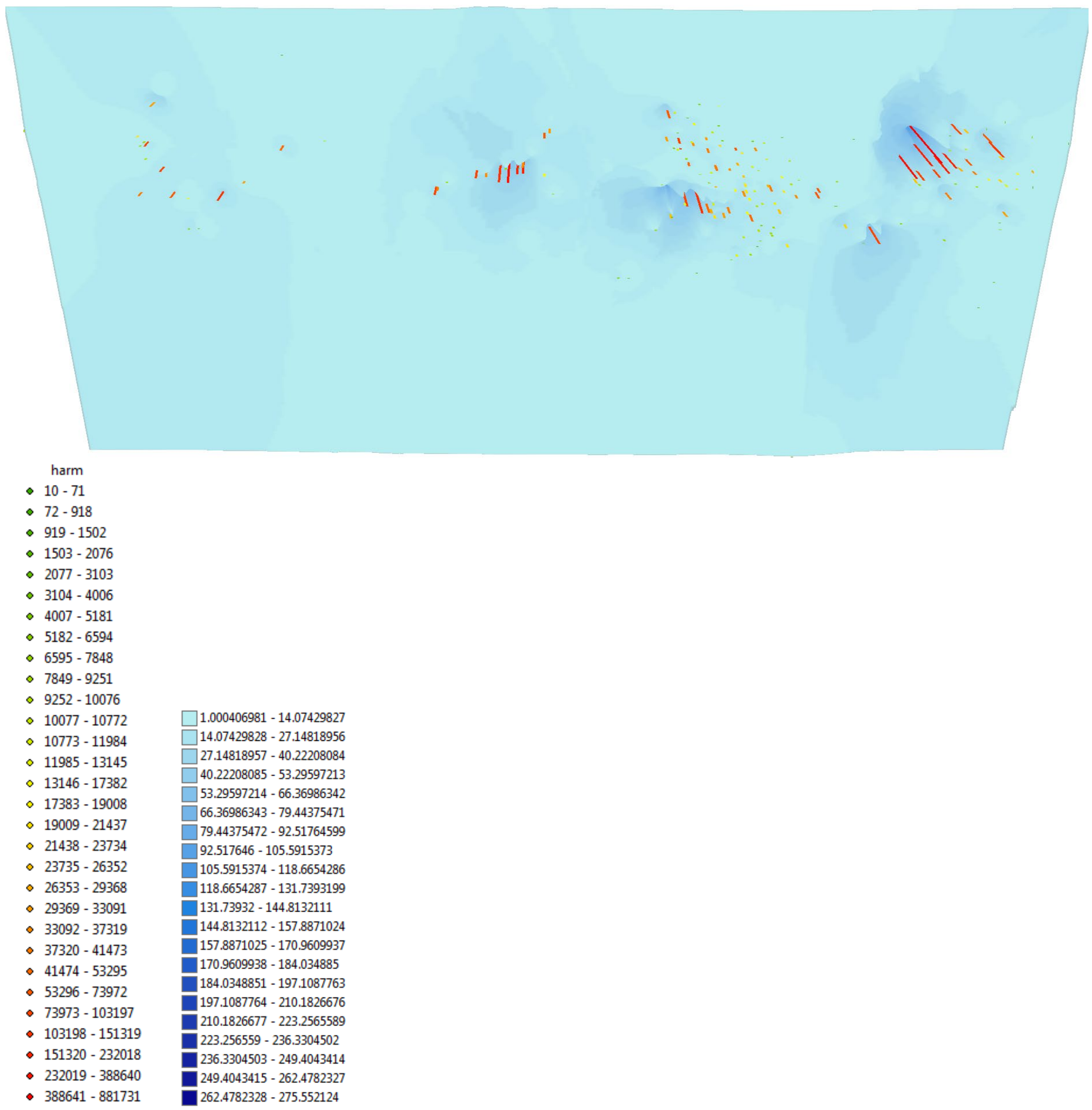


Figure 9. Power Few Grid Identified Harm, Piracy Attacks Worldwide, 2006 to 2014

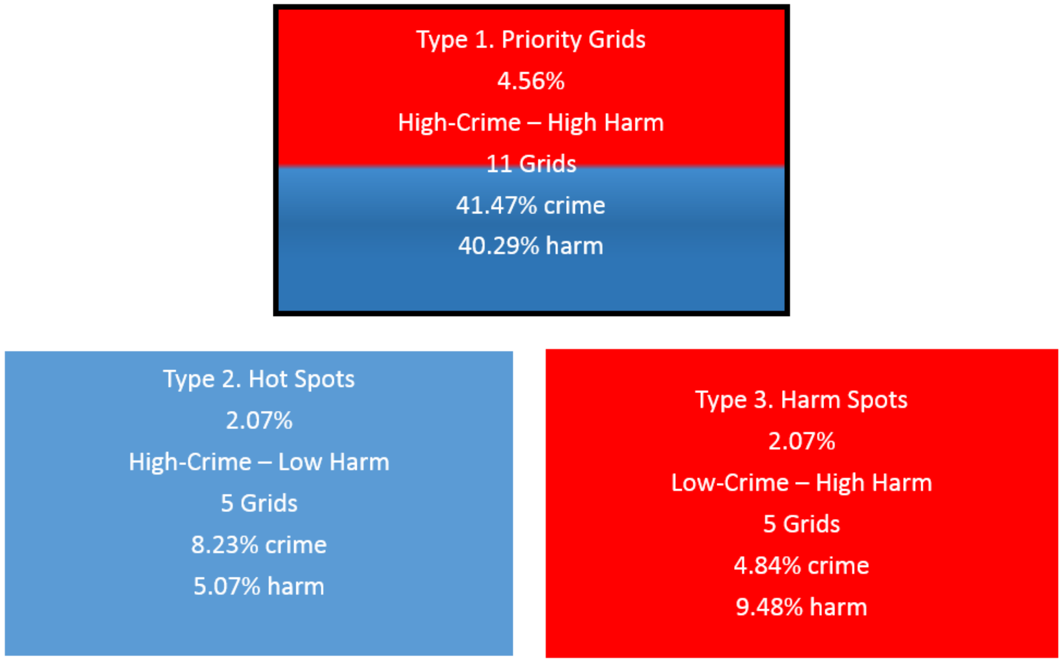


Figure 10. Cumulative Frequency of Attacks and Cumulative Harm of Attacks, Piracy Attacks Worldwide, 2006 to 2014

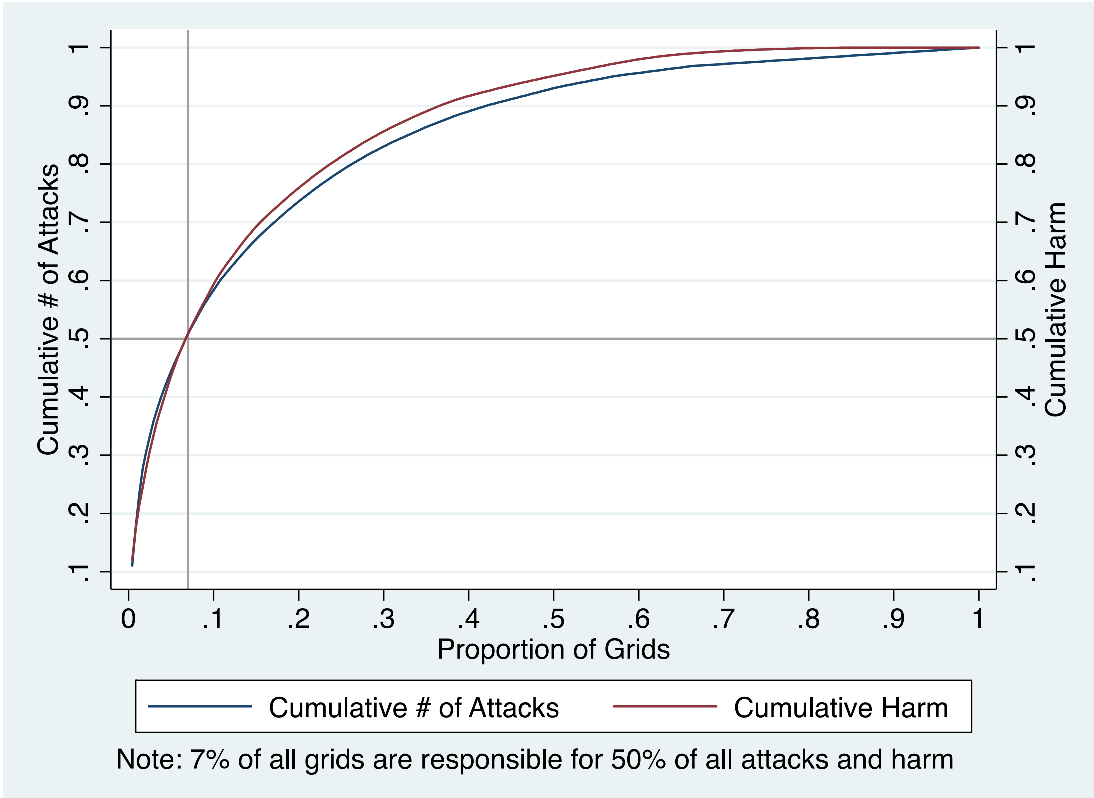


Figure 11. Power Few Grid Identified Harm, Piracy Attacks Worldwide, 2006 to 2014

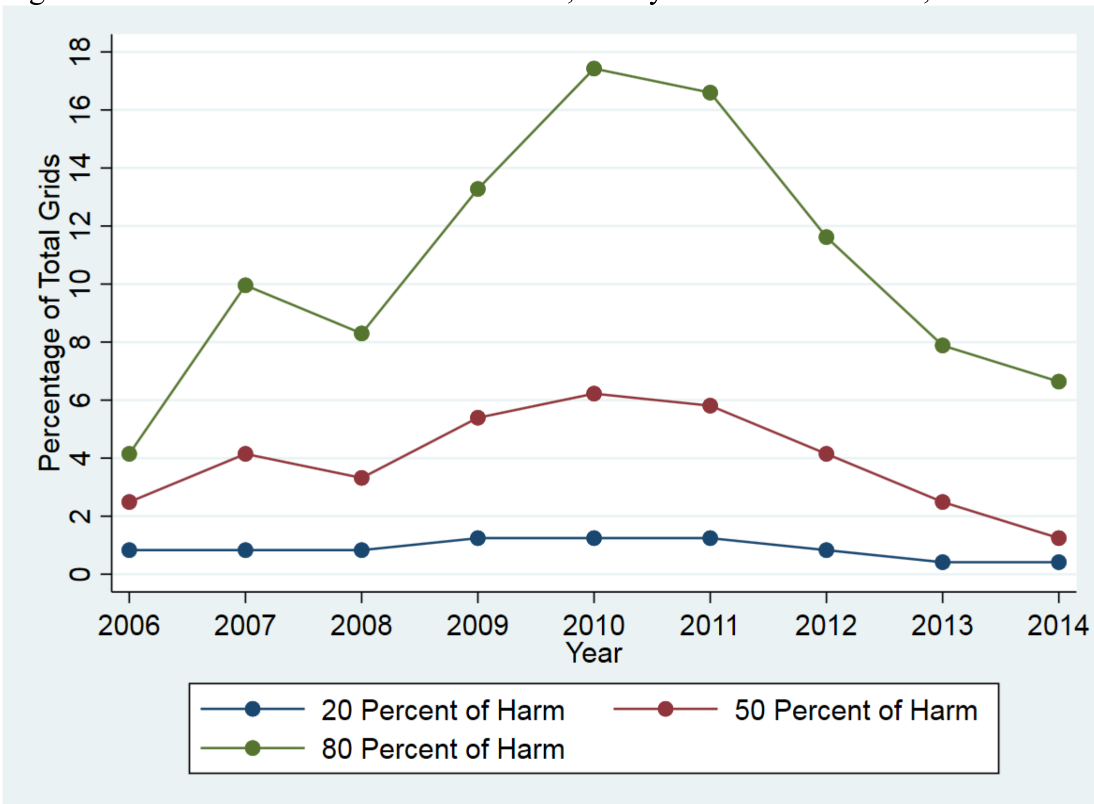


Figure 12. Power Few Grid Identified Harm (Average Crime Harm Scores per Grid), Piracy Attacks Worldwide, 2006 to 2014

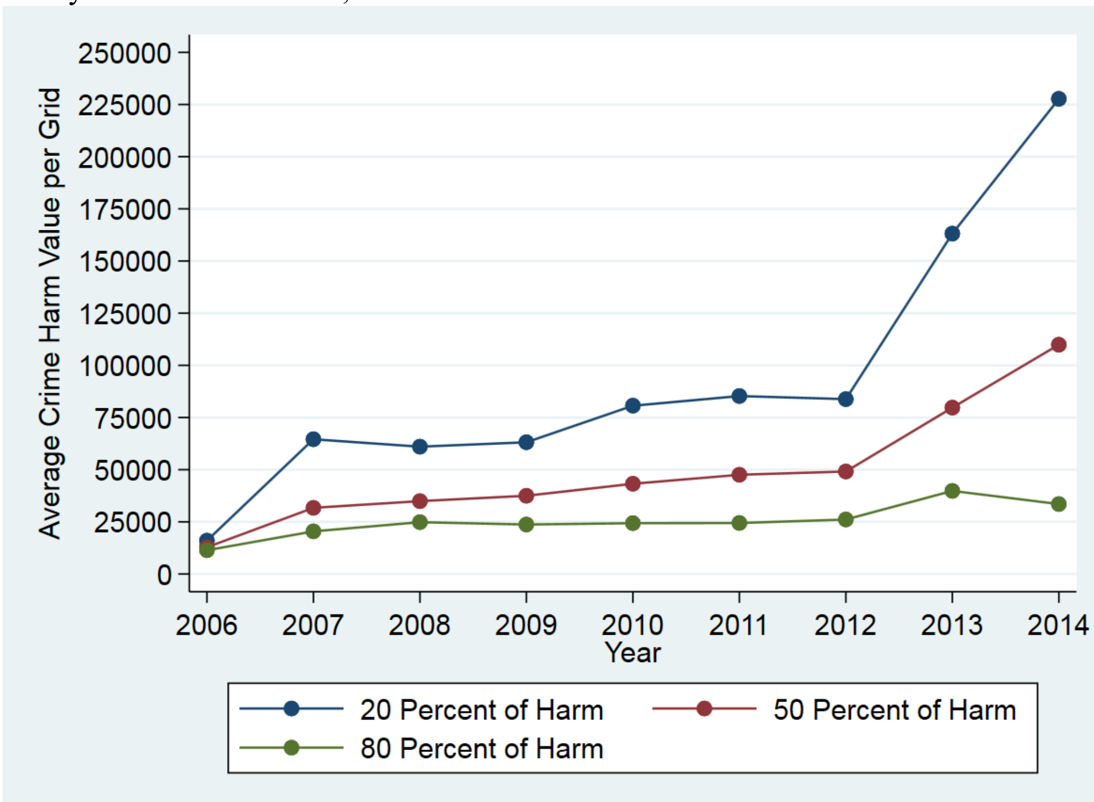


Figure 13. Piracy Attacks in Malacca Strait, 1995 to 2010

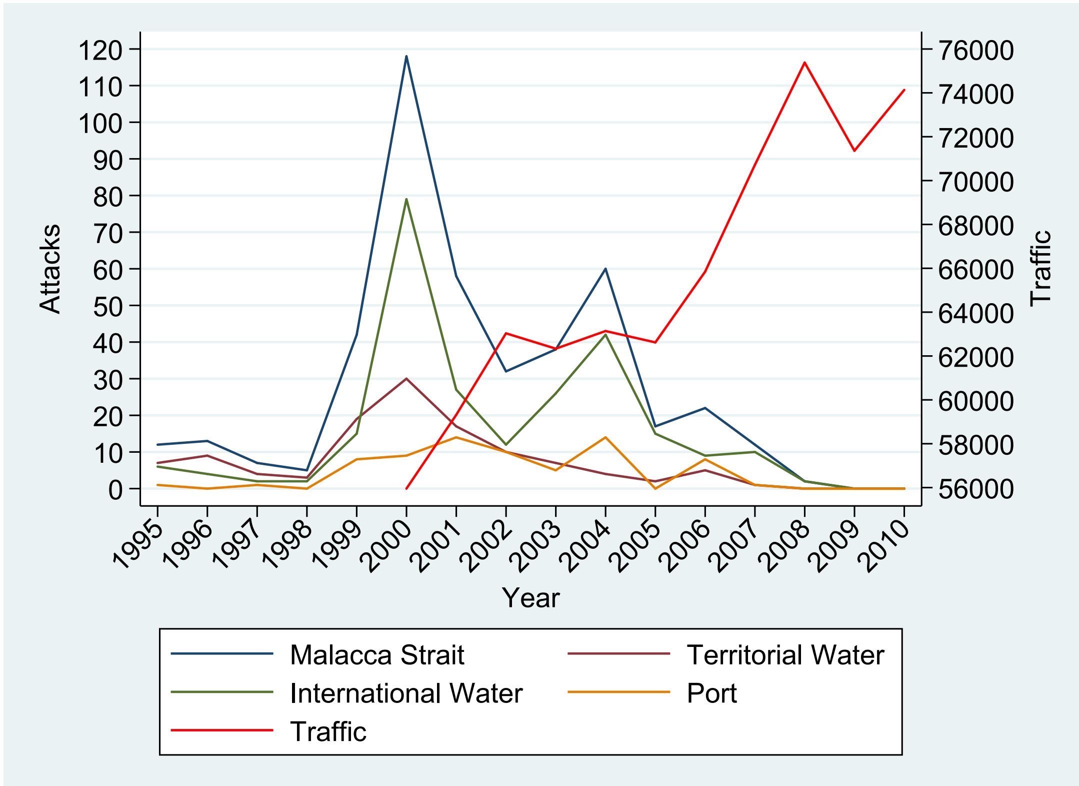


Figure 14. Piracy Attacks in South China Sea, 1995 to 2010

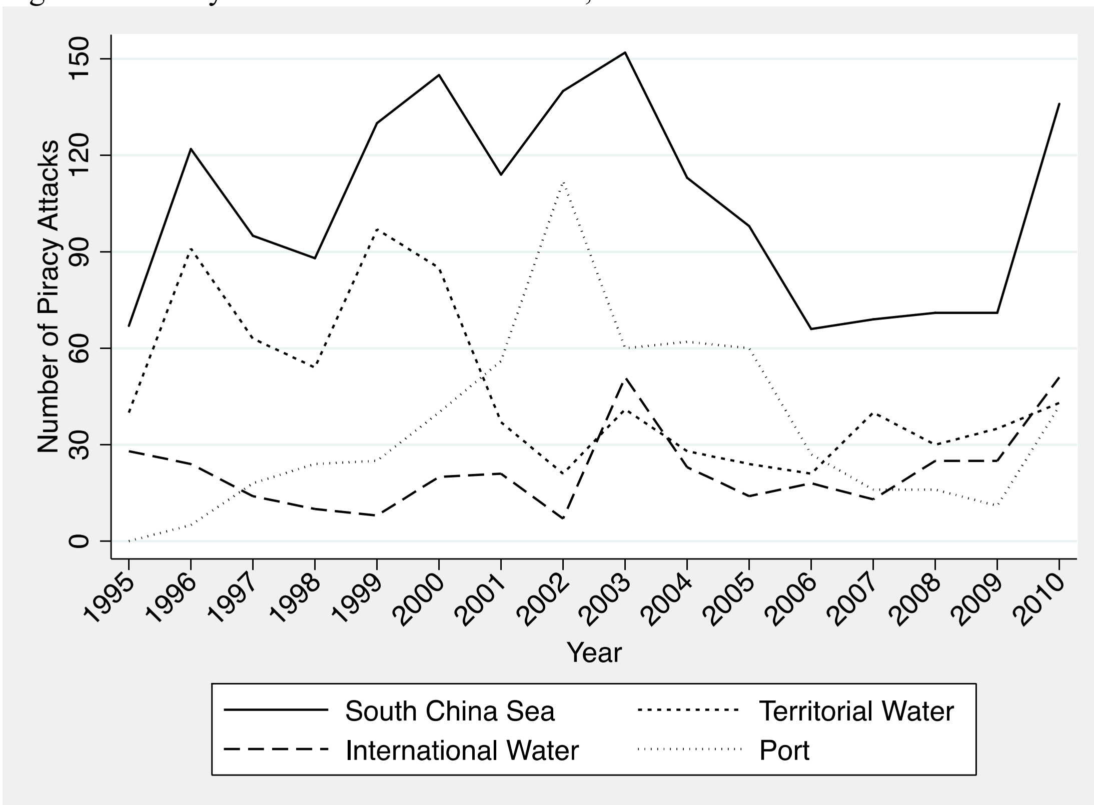


Figure 15. Graphs of the scaled Schoenfeld Residuals and their lowess smoothers for the Malacca Strait

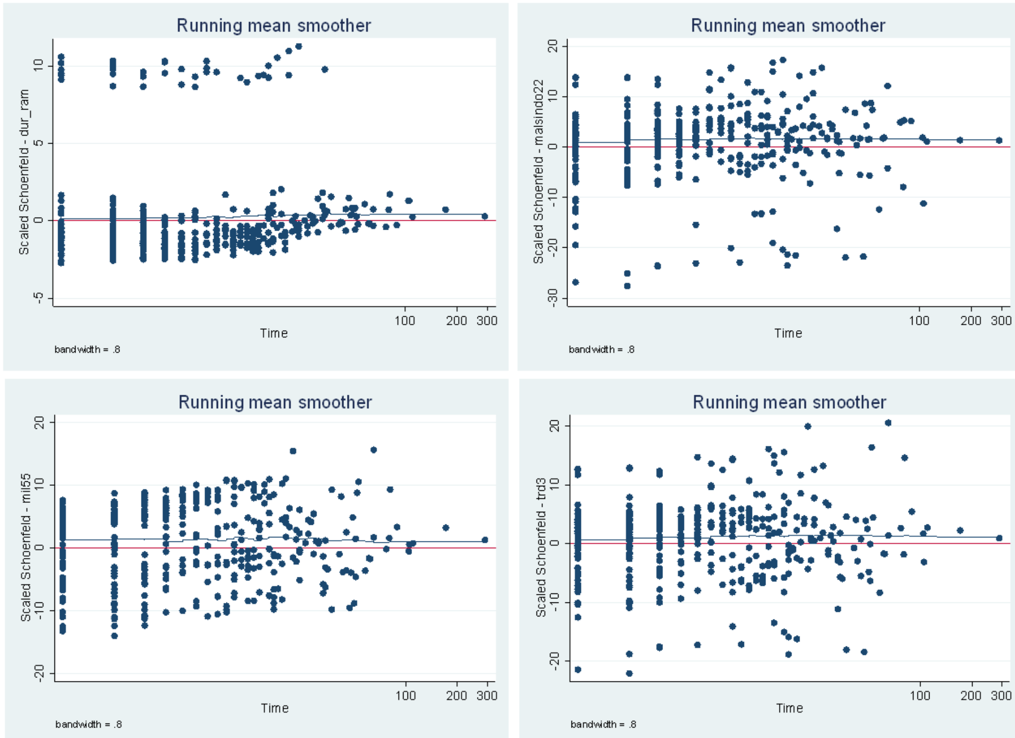


Figure 16. Graphs of the scaled Schoenfeld Residuals and their lowess smoothers for the South China Sea

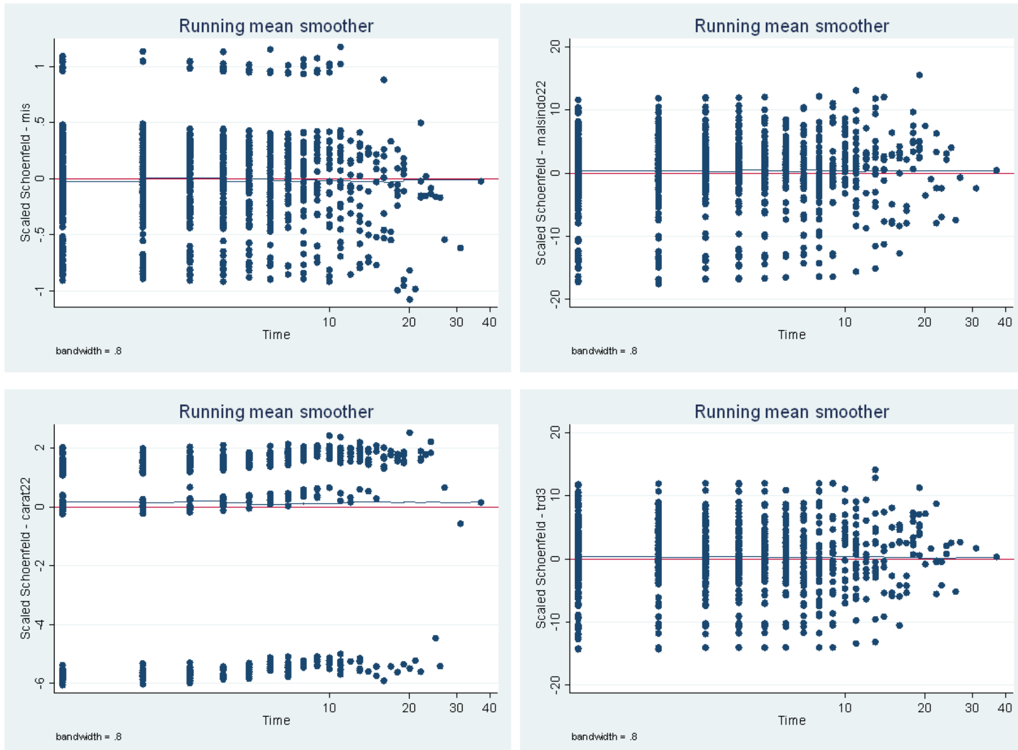
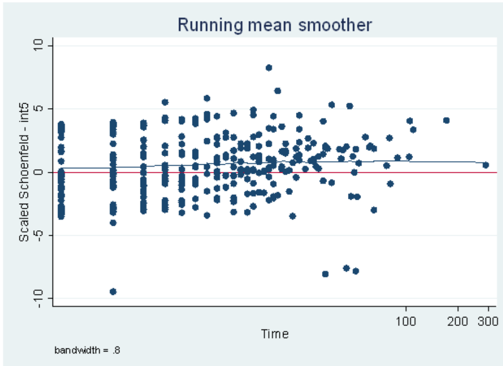


Figure 17. Graphs of the scaled Schoenfeld Residuals and their lowess smoothers for the Convergence Terms in Malacca Strait and South China Sea



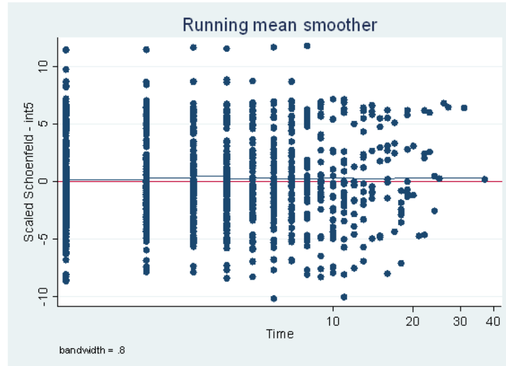


Figure 18. Trace, Correlation and Density Plots, Piracy Attacks in Malacca Strait for All Locations, 1995 to 2010

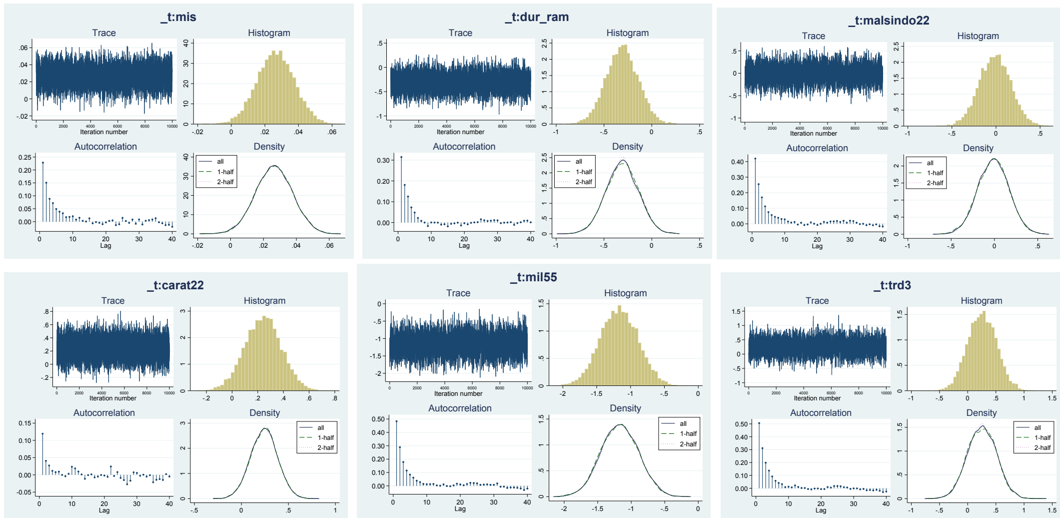


Figure 19. Trace, Correlation and Density Plots, Piracy Attacks in Malacca Strait for Territorial Water, 1995 to 2010

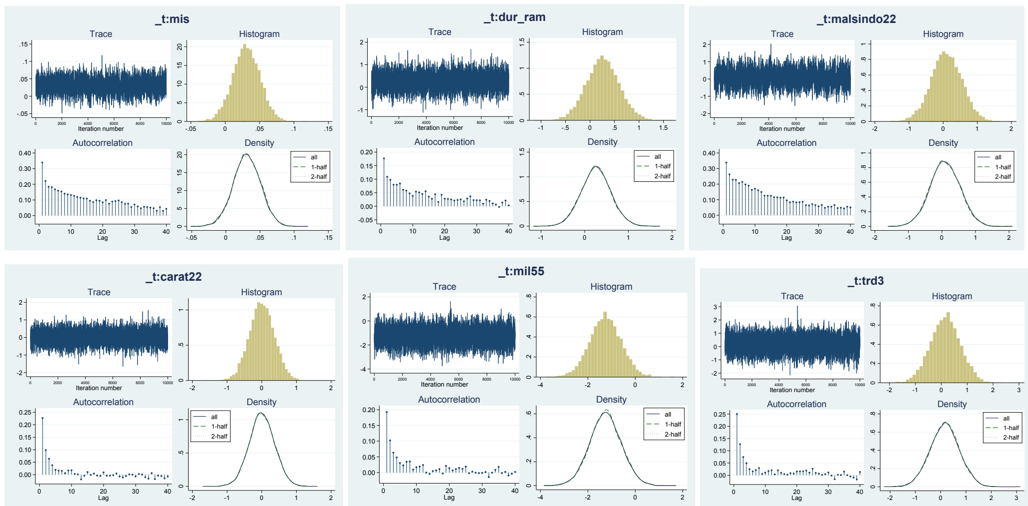


Figure 20. Trace, Correlation and Density Plots, Piracy Attacks in Malacca Strait for Port Area, 1995 to 2010

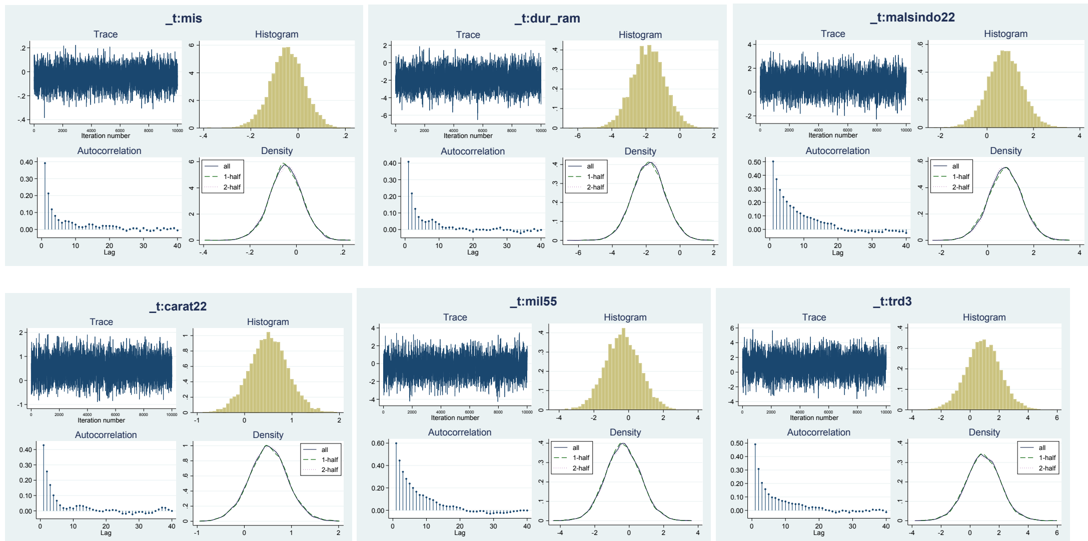


Figure 21. Trace, Correlation and Density Plots, Piracy Attacks in Malacca Strait for International Water, 1995 to 2010

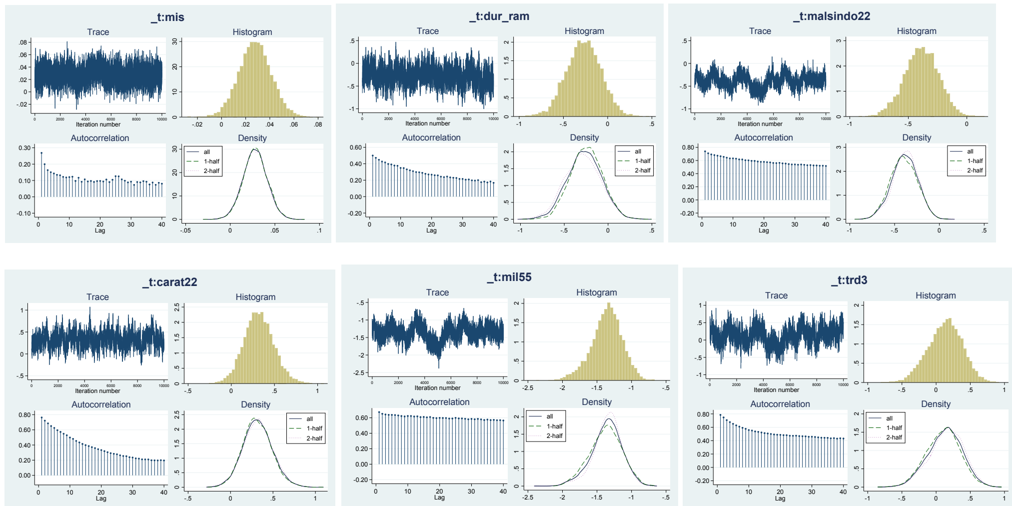


Figure 22. Trace, Correlation and Density Plots, Piracy Attacks in South China Sea for All Locations, 1995 to 2010

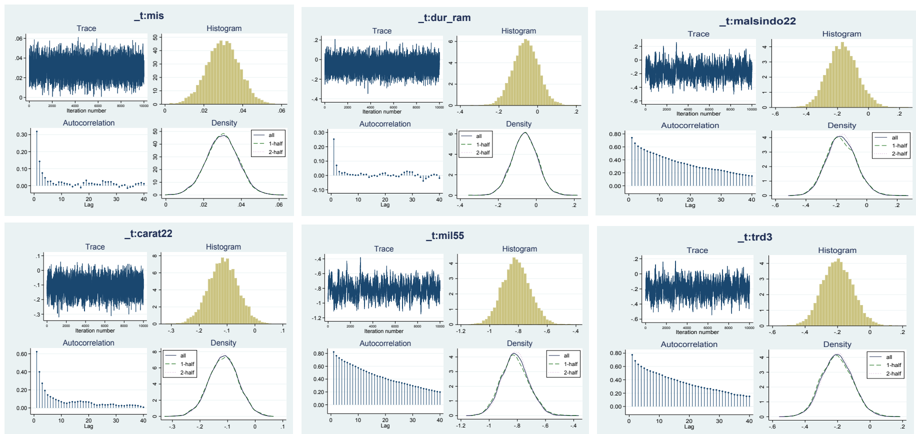


Figure 23. Trace, Correlation and Density Plots, Piracy Attacks in South China Sea for Territorial Water, 1995 to 2010

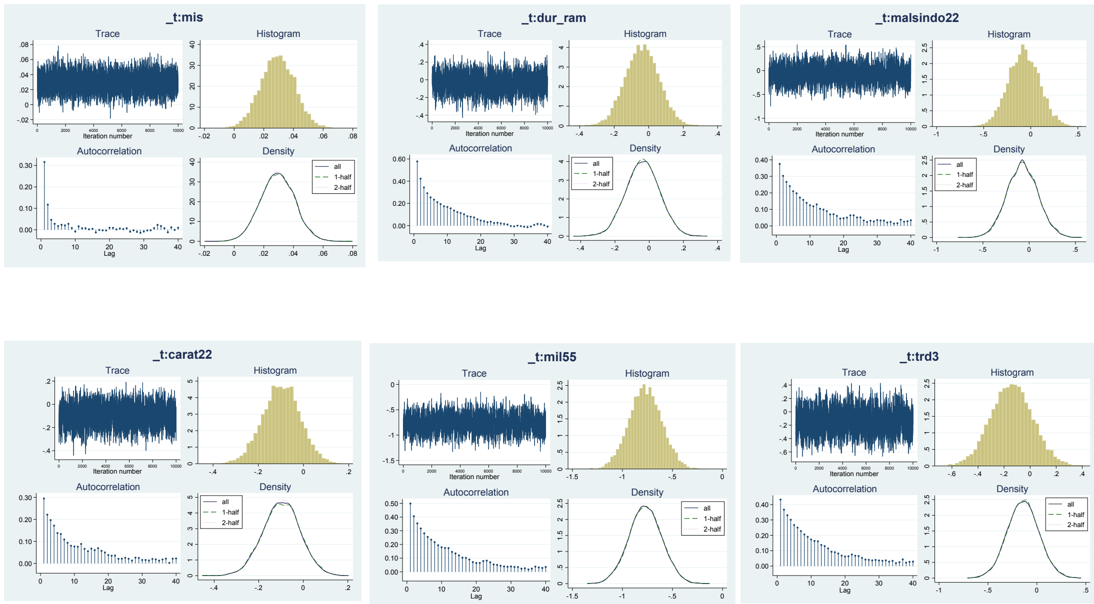


Figure 24. Trace, Correlation and Density Plots, Piracy Attacks in South China Sea for Port Area, 1995 to 2010

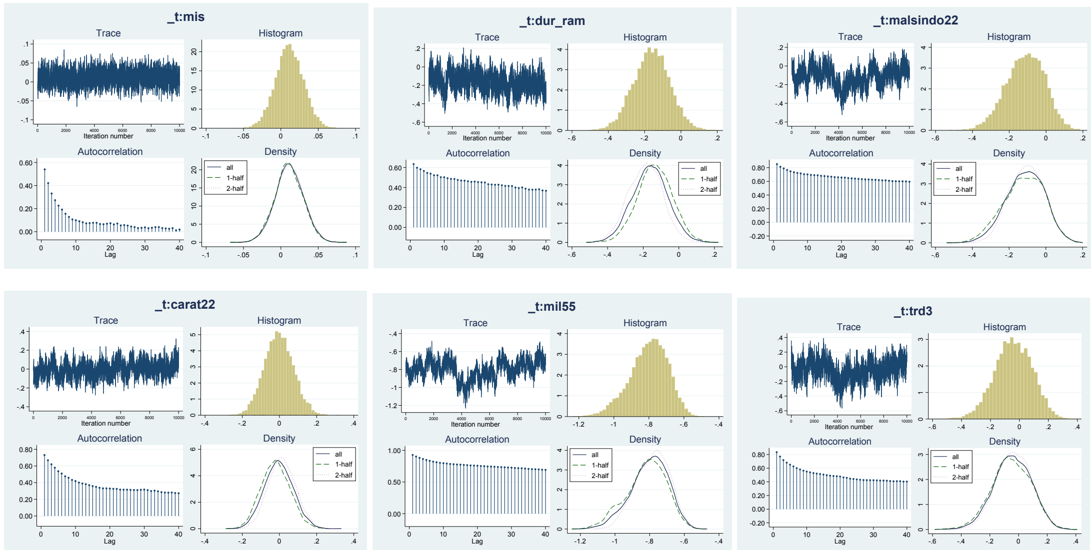


Figure 25. Trace, Correlation and Density Plots, Piracy Attacks in South China Sea for International Water, 1995 to 2010

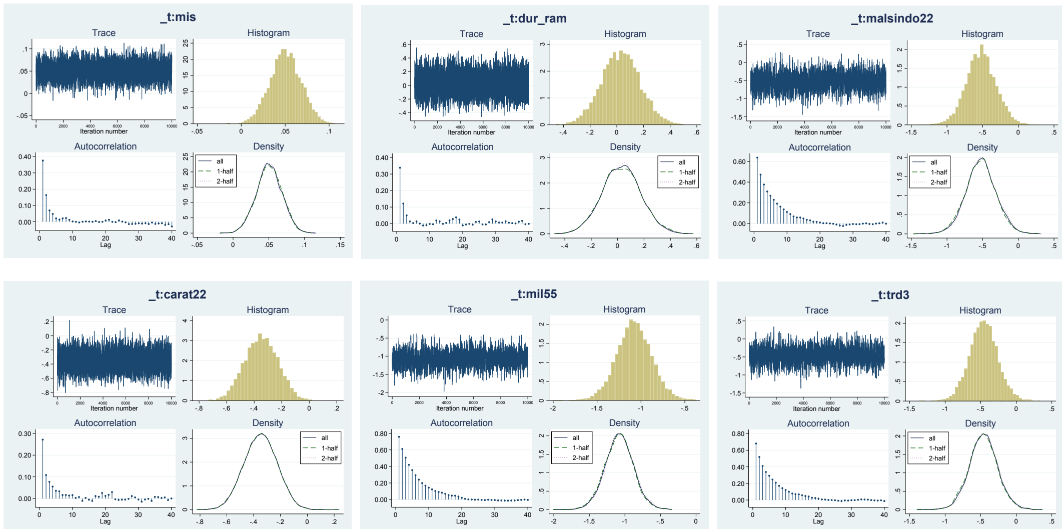
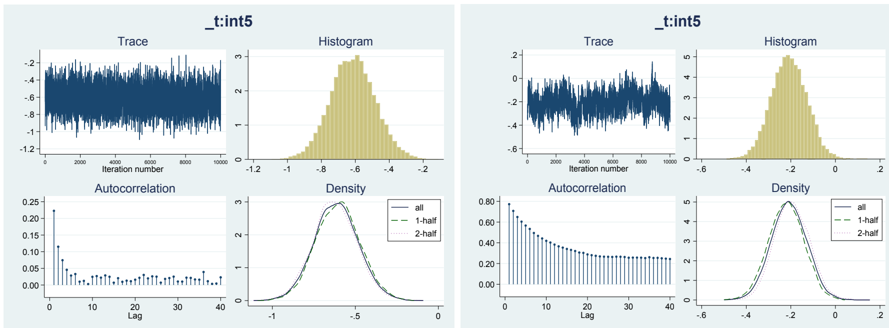


Figure 26. Trace, Correlation and Density Plots for the Convergence Terms in Malacca Strait and South China Sea



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[i] The resolution numbers are: 1814 (2008), 1816 (2008), 1838 (2008), 1844 (2008), 1846 (2008), 1851 (2008), 1897 (2009), 1918 (2010), 1950 (2010), 1976 (2011), 2015 (2011), 2020 (2011), 2077 (2012) 2125 (2013), 2184 (2014), 2246 (2015), 2316 (2016), and 2383 (2017).

[ii] Available at: https://www.theguardian.com/world/2009/jan/09/somalia-pirates-supertanker-ransom

[iii] Pristrom, Marseq's 7th Official Piracy Update Meeting, Combating Piracy Hamburg, March, Hamburg, Germany 2011.

[iv] For shipping companies, rerouting a trip from Europe to the Far East would incur an additional $15 million in chartering additional ships to maintain schedule service and another $75 million in added fuel cost.

[v] http://www.gazzettadelsud.it/news/english/79733/Fury-in-Italy-after-UN-calls-marines-case-bilateral.html

[vi] https://www.nato.int/cps/en/natolive/opinions_107022.htm?selectedLocale=en NATO. 12 February 2014.

[vii] http://www.advanfort.com/index.php?page=press-release&press=9&title=Interview%20with%20Former%20Pirate%20Alley%20Commander%20Terry%20McKnight

[viii] https://www.washingtonpost.com/world/national-security/somali-pirates-will-face-death-penalty-in-federal-trial-in-va/2013/06/02/197a8868-c969-11e2-8da7-d274bc611a47_story.html?utm_term=.b15daaa7b572

[ix] *Ali Samatar and Others v. France*, (Judgment), App. No. 17110/10 and 17301/10, Eru. 2014 Eur. Ct. H.R., available at http://hudoc.echr.coe.int/sites/eng/pages/search.aspx?i=001-148290#

[x] *Hassan and Others v. France*, (Judgment), App. No. 46695/10 and 54588/10, Eru.2014 Eur. Ct. H.R. available at http://hudoc.echr.coe.int/eng#

[xi] https://www.nytimes.com/2008/09/29/world/africa/29pirates.html?ref=world

[xii] Available at http://www.fao.org/fi/oldsite/FCP/en/som/profile.htm

[xiii] FAO Somalia, "A 5-Year Strategy and Plan of action 2011-2015". Available at http://faosomalia.org/uploads/FAO%20Somalia%205- year%20strategy.pdf

[xiv]

[xv] Mohamed Abshir Waldo, "The Two Piracies in Somalia: Why the World Ignores the Other," Wardheernews.com, January 8, 2009, http://wardheernews.com/Articles_09/Jan/Waldo /08 _The_two_piracies_in_Somalia.htm

[xvi] Najad Abdullahi, '"Toxic Waste" behind Somali Piracy' (http://english.aljazeera.net/news/africa/2008/10/ 2008109174223218644.html)

[xvii] Available at https://gisis.imo.org/Public/Default.aspx

[xviii] Available at https://www.ceicdata.com/en.

[xix] As the duration until the event shortens, the hazard increases. While the hazard function is not a probability, it can be thought of as the probability that an event will occur during a very small interval of time (Allison, 1995).
[xx] This criterion excludes earlier periods when the hazard is necessarily 0.
[xxi] In the sampling period from 1995 to 2010, Ramadan began on the following dates: February 1, 1995, January 22, 1996, January 10, 1997, December 31, 1997, December 20, 1998, December 9, 1999, November 28, 2000, November 17, 2001, November 6, 2002, October 27, 2003, October 16, 2004, October 5, 2005, September 24, 2006, September 13, 2007, September 2, 2008, August 22, 2009, August 11, 2010 and lasted for twenty nine or thirty days.
[xxii] The dates are May 12, 1998; June 28, 1999; June 14, 2000; May 17, 2001; May 1, 2002; May 28, 2003; June 12, 2004; June 15, 2005; June 14, 2006; May 12, 2007 and May 3, 2010. There is no clear record of start dates of CARAT in South China Sea for the years 1995 to 1997 and 2008 to 2009. I estimated based on the start date in Singapore, which is usually the first or last visit by the Pacific Fleet, that the start dates are May 25, 1995; May 13, 1996; May 21, 1997; July 8, 2008 and June 20 2009.
[xxiii] As an illustrative example, if there is an attack on June 7th, and then two days later there are two attacks on June 9th, then the dependent variable for the June 7th event is 2. However, the two events on June 9th will each have the same value for the dependent variable, which will make them tied.
[xxiv] Attacks on the same day are given the same Strata ID. There are 376 unique Strata IDs in the Malacca Strait. In the South China Sea, there are 1,336 unique Strata IDs.
[xxv] As explained earlier, the frequentists approach "…considers that the probability is included in the random experiment itself and appears as a stabilized relative frequency when the same random experiment is repeated independently in the same conditions, but this independence cannot be clearly defined in reality and must be subjectively accepted." (Chaput, Girard and Henry, 2011:87)
[xxvi] For details on the construction of the grids, please refer to section 5.2
[xxvii] As an example, the first panel for the variable MALSINDO is generated using the Stata command: *quietly stcox mis dur_ram mil carat malsindo trd3 candt density33 lastreported , vce(cluster id) efron nohr sca(sca*)estat phtest, log plot(malsindo) yline(0)*
[xxviii] Because of quarantine regulations, live dogs are not permitted in the next harbor

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