Climate Change, Fish Production, and Maritime Piracy

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ABSTRACT: Contemporary social science has produced little research on connections between climate change and crime. Nonetheless, much prior research suggests that economic insecurity may affect individual calculations of the cost and benefit of engaging in criminal behavior, and climate change is likely to have important economic consequences for professions like fishing that depend directly on the environment. In this paper, we test the possibility that climate change affects participation in maritime piracy, depending on the specific ways that it impacts regional fish production. Our analysis is based on piracy in East Africa and the South China Sea. These two regions are strategic in that both areas have experienced a large amount of piracy; however, rising sea temperatures have been associated with declines in fish production in East Africa but increases in the South China Sea. We treat sea surface temperature as an instrument for fish output and find that in East Africa higher sea surface temperature is associated with declining fish production, which in turn increases the risk of piracy, whereas in the South China Sea higher sea surface temperature is associated with increasing fish production, which in turn decreases the risk of piracy. Our results also show that decreases in fish production bring about a larger number of successful piracy attacks in East Africa and that increases in fish production are associated with fewer successful attacks in the South China Sea. We discuss the theoretical and policy implications of the findings and point out that as climate change continues, its impact on specific crimes will likely be complex, with increases and decreases depending on context.

SIGNIFICANCE STATEMENT: There is little evidence on the effect of climate change on criminal behavior. This study seeks to quantify the impact of a specific type of climate change—rising sea temperature—on maritime piracy, a type of crime that is linked exclusively to the ocean. The risk of piracy attacks and the probability of successful attacks are higher with declines in fish production in East Africa and lower with increases in fish production in the South China Sea. These results suggest that climate change does affect maritime piracy rates and that its effect depends on the specific situational context and the rational choices that changing sea temperatures generate.

KEYWORDS: Social science; Crime; Sea surface temperature; Africa; Asia; Regression analysis

1. Introduction

Despite growing interest in climate change and the mounting evidence that it has the potential to affect crime, with few exceptions (Agnew 2012; LeBeau 1994; Rotton and Cohn 2003), social science has produced little work in this area. A likely impact of climate change on crime is a shift in the rewards for criminal behavior as rising temperatures affect diverse outcomes including agricultural production (Barrios et al. 2010; Blakeslee and Fishman 2014), fishing (Brander 2010), the frequency and severity of weather-related emergencies (Jacob et al. 2007; Ranson 2014), and international migration (Barrios et al. 2006; Feng et al. 2012).

We employ Becker's (1968) rational choice perspective to help understand the effects of climate change on maritime piracy. Rational choice arguments seem especially well suited for explaining both the costs and rewards of maritime piracy. There is strong qualitative evidence that fishers move back and forth between conventional (fishing) and criminal (piracy) behavior depending on economic conditions (Ellerman et al. 2010; Frécon 2006). Moreover, because piracy requires specialized skills that are most common for those who make their living on the sea (Daxecker and Prins 2013; Liss 2011; Murphy 2009), the choice to engage in maritime piracy is likely to be disproportionately attractive to those with seafaring expertise.

We examine the impact of a specific type of climate change—rising sea temperature—on maritime piracy in two regions of the world, both of which have been plagued by high levels of piracy: East Africa and the South China Sea. As compared with studies examining a diverse range of outcomes related to crime and security on land, we argue that the effects of climate change are transmitted most directly to individuals whose livelihood is connected to the ocean. Based on rational choice theory, we expect maritime piracy to be linked directly to the costs and rewards of fishing. We measure climate change by examining satellite data on sea surface temperature and the economic rewards of piracy by measuring total fish production. Most prior research on connections between climate change and piracy has been based on qualitative (Ellerman et al. 2010; Frécon 2006) or nonexperimental quantitative analysis

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(Flückiger and Ludwig 2015; Tominaga 2018). What is especially interesting about our two case studies is that climate change has had opposite effects on fish production in the two regions; rising sea temperature is associated with declining fish production in East Africa but increasing fish production in the South China Sea. Hence, we have a rare opportunity to look at connections between climate change and a type of crime that includes predictions in opposite directions. Moreover, we improve on prior studies by using sea temperature as an instrument for fish production, providing a more defensible response to the likely endogeneity between fish production and piracy.

Based on rational choice theory we predict that piracy will increase in East Africa along with increases in the market pressures caused by declining fish output and will decline in the South China Sea along with decreases in the market pressures related to increasing fish output. We discuss the theoretical and policy implications of climate change for maritime piracy and emphasize the fact that climate change is likely to have complex effects, increasing crime in many environmental contexts, but also, perhaps occasionally, leading to crime declines.

Our paper proceeds in four sections. We begin by defining maritime piracy, visualizing the distribution of piracy attacks in the two regions, and reviewing the expected effects of climate change on fish production and maritime piracy. Second, we offer our hypotheses that declining fish production will be linked to increases in maritime piracy while increasing fish production will be related to decreases in piracy in the two regions being studied. Third, we provide a description of the data and empirical strategy, including a discussion of the variable that we use as an instrument and how the dependent and control variables are measured. Last, we discuss the results and conclude with theoretical and public policy implications.

2. Maritime piracy in the South China Sea and East Africa

According to Article 101 of the United Nations Convention on the Law of the Sea (UNCLOS) "piracy" is defined as

> (a) any illegal act 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 against persons or property on board such ship; (ii) against a ship, 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; and (c) any act of inciting or of intentionally facilitating an act described in subparagraph (a) or (b) (Fieducik 2011, p. 1).

Although maritime piracy has been a problem since at least the fifth century BCE (Murphy 2012), the world has experienced its resurgence in recent decades, particularly in the regions of the South China Sea and the western Indian Ocean. For the past two decades, violent attacks on ships and large ransom payments to secure the safe release of crew members have become common.[1] Given that 90% of the world's traded goods are transported by sea (Bowden et al. 2010), piracy poses a huge threat to the world economy and global trade. The study estimates that piracy raises annual shipping costs by USD 7–15 billion per year.

The International Hydrographic Organization (1953, 30–31) defines the limits of the South China Sea as bounded on the north by China, on the east by the Philippine islands, on the south by the Indochinese Peninsula, and on the west by the Malay Peninsula and Vietnam. The South China Sea is connected to the Indian Ocean through the Malacca Strait, which is 885 km long, reaches a width of 400 km in the north and 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 have created challenges for both maritime security and management. The International Chamber of Shipping estimates that, since 2000, more than 70 000 merchant ships (weighing at least 300 gross tons each) carry one-half of the world's trade cross the South China Sea every year. Connecting the Indian Ocean with the South China Sea, the Malacca Strait is one of the world's busiest shipping lanes; it is strategically important because it links these areas to the Pacific Ocean.

The Gulf of Aden is a strategic shipping route connecting the Indian Ocean and the Mediterranean Sea. More than 80% of the trade transiting the gulf is with Europe, and, for the last decade, the value of Asia–Europe trade increased from EUR 900 000 million to more than EUR 1 400 000 million. The gulf is also a strategic chokepoint for the export of Persian petroleum to Europe, the United States, and Asia. Birtchnell et al. (2015) estimate that 3.8 million barrels of petroleum products and crude oil passed through the gulf every day in 2013. The authors note that the number of vessels transiting the gulf averaged 20 000 annually during the late 2000s. We argue that the emergence of economically lucrative targets traveling close to land at low speed, combined with hardships experienced on land near the major shipping lanes and a dearth of capable guardians, make piracy tempting in these regions.

In Fig. 1a, we illustrate the patterns of concentration of piracy attacks worldwide from 2006 to 2015. We found 241 3° × 3° grids with at least one attack and that, of these, 16 grids alone (or 6.64% of grids with at least one attack) generated 49.7% of all attacks. Seven of these 16 grids were located in the South China Sea, 1 in the East Indian Ocean, 4 in the western Indian Ocean and 4 in West Africa. The blue dots in Fig. 1b show the piracy attack centroids for the Malacca Strait, the South China Sea, the Indian Ocean, and East and West Africa. The centroids generally fall into four main hotspots—Malacca Strait and South China Sea, Indian Ocean, Gulf of Aden, and West Africa. Figure 1 clearly shows that the patterns of piracy attacks in these areas are strongly clustered.

3. Choosing between fishing and maritime piracy

Prior research (Daxecker and Prins 2013; Frécon 2006; Liss 2011; Murphy 2009) shows that pirates often have a background in fishing, which gives them a natural advantage in getting acquainted with local patterns of maritime traffic. It is reasonable to speculate that the rewards of piracy will be

[1] For example, the *New York Times* published more than 300 articles related to the topic "piracy at sea" during the past 10 years.

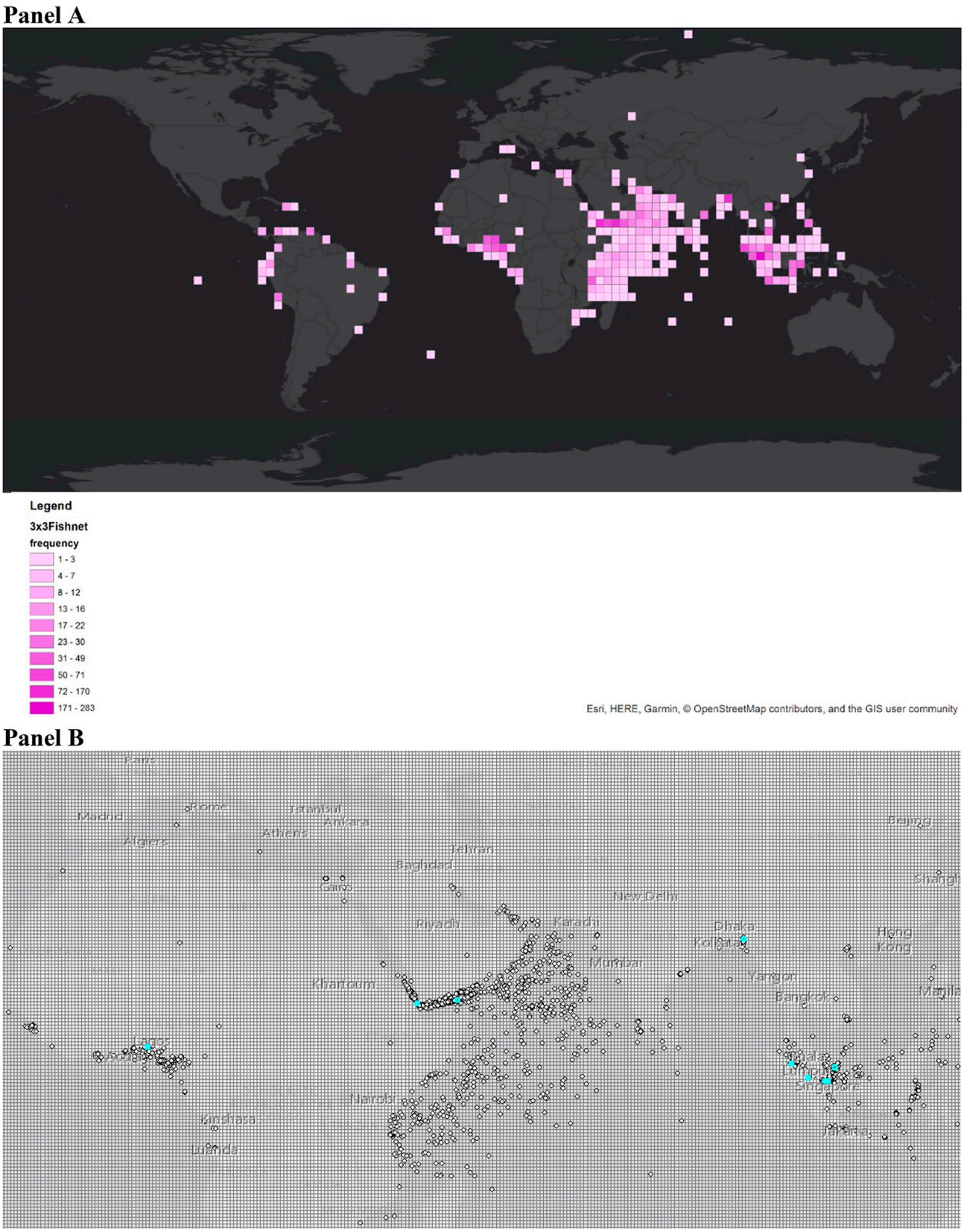

FIG. 1. Visualization of piracy attacks worldwide: (a) the frequency distribution of piracy attacks in 3° × 3° grids with at least one piracy attack for 2006–15, and (b) the centroid of piracy attacks for each region.

linked to fishing conditions. Ellerman et al. (2010) aptly refer to their case studies of fishers who engage in piracy to make ends meet as "occasional pirates" and point out that for these individuals, "piracy was typically a seasonal job . . . fishermen turned to piracy to supplement their incomes from lawful activities." Similarly, in interviews with Indonesian pirates, Frécon (2006) concludes that criminal syndicates engaged in maritime piracy most often recruit unemployed fishers and sailors. He calls these fishers "part-time pirates" or "standby pirates." In general, this reasoning suggests that piracy is a rational response to financial insecurity brought about by the declining availability of fish. In some cases, this rationale for criminal behavior may receive community support. Thus, in a study of Somali pirates, Schneider and Winkler (2013) conclude that piracy, including the kidnapping of crew members, is culturally accepted and interpreted by many locals as a form of taxation to make up for the loss of fish. This interpretation is confirmed in a Somali study by Schbley and Rosenau (2013) who conducted interviews with government leaders and United Nations officials.

Although a connection between economic conditions and piracy has long been suggested by qualitative studies (Bueger et al. 2011; Ellerman et al. 2010; Frécon 2006; Schneider and Winkler 2013), rigorous statistical testing of this association is recent (Daxecker and Prins 2013; Flückiger and Ludwig 2015; Jablonski and Oliver 2013). Jablonski and Oliver (2013) argue that reduced prices for agricultural products increases economic stress and thus lowers opportunity costs for engaging in piracy. Similarly, Daxecker and Prins (2013) show that the annual frequency of pirate attacks is inversely related to the growth of fish production. Unfortunately, these studies fail to address the potential endogeneity between fish production and the frequency of pirate attacks. If the key independent variable is endogenous (i.e., fish production is correlated with the error term), regression analysis cannot consistently estimate the causal effect of fish production on the incidence of piracy (Angrist and Krueger 2001). Thus, earlier studies cannot rule out the possibility that the increased probability of being attacked by pirates may discourage legal fishing: that is, increased piracy reduces fish production rather than the reverse.

Flückiger and Ludwig (2015) attempt to resolve the endogeneity problem in explaining the link between piracy and fish production by using phytoplankton abundance as an instrument for fish production. Using satellite grids as their unit of analysis, they show that the abundance of plankton is positively related to fish production, but negatively associated with the incidence of piracy. They conclude that a decline in plankton that reduces fish production by 10% also increases the risk of piracy by 10%. Similarly, Tominaga (2018) responds to the endogeneity between maritime fisheries and piracy by using photosynthetic plankton to instrument fish production. Across four models, the author finds consistent evidence for a negative relationship between fish output and piracy attacks.

However, while these are innovative responses to the endogeneity problem it seems unlikely that plankton or photosynthetic plankton abundance is truly exogenous to the risk of being pirated. For example, we might expect that these microorganisms are adversely affected by coastal environmental degradations such as dumping of toxic waste, which in turn is most likely related to variables such as poor economic conditions and a lack of effective governance. Thus, the exogenous variable plankton abundance, which is supposed to be only correlated with the endogenous variable fish production, is likely correlated with the error term.

In another recent study, Axbard (2016) relies on satellite data of environmental conditions, including wave height, wind speed and precipitation variations to serve as instruments to resolve the endogeneity between fish production and piracy. He uses the local price of fish to measure fish availability and analyzes geospatial data on pirate attacks and environmental conditions for $2° \times 2°$ grids covering the exclusive economic zone (EEZ) of Indonesia. The results show that environmental conditions that are favorable for fishing reduce the risk of pirate attacks by 40%.

Although Axbard's study resolves common identification problems, his research has at least two important limitations. First, the study is limited to the EEZ of Indonesia. Research on maritime piracy in Southeast Asia (Liss 2011) and elsewhere (McCabe 2017) demonstrates that piracy reporting practices and target types between pirate attacks that were perpetrated near the port area (within the EEZ) and in international waters were systematically different. Second, the local market price of fish in some countries and at some points in time may not serve as an appropriate measure of fish availability and fishing conditions (Powell et al. 2008). For example, Axbard's estimation strategy may not be generalizable to Somalia, a failing state and a notorious piracy hotspot (Lindley 2016; Weldemichael 2019).

In sum, the empirical literature has primarily used aggregated annual time series data and focused on the counts of piracy in waters around a single country using instruments that are less than ideal. Furthermore, past work has seldom evaluated the effects of changes in economic conditions on the instantaneous risk of piracy. Bearing these limitations in mind, we develop an identification strategy that does not rely on a price mechanism such as economic stress. Also, instead of focusing on waters around a single country, we study two large regions so that we can include not only pirate attacks committed in port areas and territorial waters, but also those occurring in international waters.

4. The effects of climate change on fish production

Fish are "poikilothermic," which means that they lack the ability to regulate their body temperature through physiological processes and must instead maintain their temperature by changing their behavior (Heinrich 1977; Howell et al. 2010; Pang et al. 2011). However, there is great variation in terms of how changing environmental conditions affect the worldwide availability of different species of fish. Studies show that rising sea temperature along the equator encourages fish species to migrate in the direction of the poles in search of cooler water (Ayub 2010; Shuter and Post 1990). Similarly, the survey by Logerwell et al. (2015) of Arctic fish communities found that

TABLE 1. Data structure, frequency, and measurement for variables included in the analysis.

Variable	Data structure	Frequency	Measurement	Source
Days until next attack	Continuous	Event specific	Time	IMO GISIS
Success	Binary	Event specific	Ship level	IMO GISIS
SST	Continuous	Monthly	Regional (std dev for each grid cell)	NOAA ERSST
Fish production	Continuous	Yearly	Regional (million tons)	FAO FishStatJ
Economic stress index	Continuous	Yearly	Regional (percent)	CEIC Data, Ltd.
Regional trade	Continuous	Quarterly	Regional (USD millions)	CEIC
Merchant ship	Binary	Event specific	Ship level	IMO GISIS
Private security guard	Binary	Event specific	Ship level	IMO GISIS
Success density	Continuous	Event specific	Authors' calculation	IMO GISIS
Last reported	Binary	Event specific	Ship level	IMO GISIS
Rule of law	Continuous	Yearly	Regional (−2.5 weak; 2.5 strong)	CEIC
Political stability index	Continuous	Yearly	Regional (−2.5 weak; 2.5 strong)	CEIC
Corruption perceptions index	Continuous	Yearly	Regional (100 = no corruption)	CEIC

some species were expanding their range to the north. For instance, data from 2007 to 2012 in the Beaufort and Chukchi Seas showed that there was an unprecedented invasion of Arctic rivers by Chinook salmon. In Portugal, Gamito et al. (2016) discovered that 18 new fish species from tropical or subtropical waters can now be found offshore in northern Portugal. The authors claim that this pattern is consistent with the northward shift of tropical species in response to ocean warming. However, Pinsky et al. (2013) analyzed more than 350 types of marine organisms and discovered that fish migration patterns do not always track northward in response to rising temperature. In both the Gulf of Maine and the Gulf of Alaska, fish appear to be migrating south as a result of the cycle of Pacific Ocean warming.

Herrod-Julius and McCarty (2002) warn that fisheries are particularly vulnerable to fluctuations in sea temperature. They further claim that sea temperature change will likely be one of the leading variables associated with the collapse of some types of fish species and the expansion of others. This line of reasoning implies that the regional impact of sea temperature change on fish production can be either adverse or beneficial. Wenger et al. (2011) state that an increase in water temperature in high latitudes leads to increased growth rates in fish production. However, this is not the same with the tropics where fish species are already near their maximum tolerance range.

In short, prior research shows that fish seek environments that optimize their conditions for growth, foraging success and survival (Comte et al. 2014; Herrod-Julius and McCarty 2002). Given that fish cannot physically regulate their body temperature, they are strongly dependent on fluctuations in sea temperature. While some species of fish may be reproductive "winners" from increased temperature (Wenger et al. 2011), others have been shown to be "losers" (Selong et al. 2001). We were able to identify two areas of the world that have substantial rates of piracy but where sea temperature change has had opposite effects on total fish output: East Africa and the South China Sea.

In this paper, we propose sea surface temperature as an instrumental variable to assess the effects of changes in fish production on the instantaneous risk of being pirated and the probability of successful piracy attacks. We expect piracy to increase in the region where climate change has reduced fish production and decrease in the region where climate change has increased fish production. Our strategy directly confronts typical endogeneity problems because, although climate change is closely related to fish production, it is an exogenous source of variation with respect to being pirated.

5. Data

Our analysis is based on 1049 and 1831 pirate attacks in East Africa and the South China Sea, respectively. The dependent variable is the time (logged number of days) between piracy attacks while the independent variable is the yearly total weight (in millions of tons) of all types of fish produced/captured. We obtained the data from the International Maritime Organization Global Information Shipping System (GISIS) database. The time series for fish output measures total fish production at the time of each attack for all of the littoral countries in both regions reported to the Food and Agricultural Organization of the United Nations Global Fishery and Aquaculture Production Statistics. In Table 1, we provide a summary of the data structure, frequency, and measurement for all of the variables in the analysis.

a. Dependent variable

In Table 2, we present the descriptive statistics for the dependent and control variables across the two regions.[2] Our dependent variable is the duration, or the number of days between piracy attacks.[3] We argue that using the days between attacks to quantify the effect of climate change on the risk of being pirated has at least three advantages over traditional time series models. First, this estimation strategy allows us to use all of the available variations in the data to estimate the parameters of interest. In comparison, a yearly time series of

[2] The largest pairwise correlation for East Africa is 0.208 ("last reported" and "economic stress index"), and that for the South China Sea is 0.432 ("last reported" and "trade"). Therefore, multicollinearity is not likely to be an issue in our analysis.

[3] Because the log of 0 is undefined, we added a very small number 0.001 to the dependent variable for attacks with a duration of 0.

TABLE 2. Descriptive statistics for piracy attacks in East Africa and the South China Sea.

	East Africa				South China Sea			
	Mean	Std dev	Range	N	Mean	Std dev	Range	N
Dependent variables								
Days until next attack	4.973	9.851	[0.001, 111]	1049	5.289	11.576	[0.001, 289]	1831
Success	0.361	0.481	[0,1]	1049	0.627	0.483	[0, 1]	1831
Instrument								
SST (No. of std dev from mean)	0.909	0.478	[−0.574, 2.109]	1049	0.348	0.849	[−1.621, 2.485]	1831
Independent variable								
Fish production (million tons)	2.002	0.085	[1.818, 2.257]	1049	22.939	9.689	[4.772, 30.051]	1831
Controls								
Private security guard	0.196	0.397	[0,1]	1049	0.015	0.123	[0, 1]	1831
Economic stress index	94.775	12.27	[66.628, 117.354]	1049	10.531	4.622	[4.159, 47.178]	1831
Regional trade	2.445	0.529	[0.914, 3.1]	1049	1.043	0.347	[0.676, 2.418]	1831
Merchant ship	0.855	0.352	[0, 1]	1049	0.498	0.500	[0, 1]	1831
Success density	18.569	42.588	[0, 365]	1049	37.843	58.914	[0, 365]	1831
Last reported	0.816	0.388	[0, 1]	1049	0.711	0.453	[0, 1]	1831
Rule of law	−0.659	0.041	[−0.704, −0.49]	1049	0.153	0.054	[0.087, 0.232]	1306
Political stability index	−0.593	0.045	[−0.632, −0.348]	1049	0.012	0.084	[−0.095, 0.163]	1306
Corruption perceptions index	30.035	0.755	[29, 32.5]	1049	—	—	—	—

the counts of piracy attacks relies on the aggregation of all events in a given year. Several studies have found evidence of aggregation bias when duration data are summed to different levels (Alt et al. 2001; Shellman 2004). Moreover, four of our controls (reported to law enforcement, private security guard, merchant ship, and success density) are coded at the event level. Second, our choice of the dependent variable preserves the date of each event and allows us to directly model the dependency between events. By contrast, the temporal ordering of events is lost in longitudinal models that treat counts of piracy attacks as the dependent variable. Last, in comparison with standard time series models, we achieve more statistical power when using duration rather than attacks per year or month as the dependent variable.

b. *Instrument variable*

We use sea surface temperature (SST) as our instrument: an exogenous source of variation with respect to the risk of being pirated that is correlated with fish production but not with the error term. Monthly SST data are from the National Oceanic and Atmospheric Administration's Extended Reconstructed Sea Surface Temperature (NOAA–ERSST) data, available at a resolution of 1° × 1°. We note that the long-term SST monthly mean (°C) is generally higher for the South China Sea when compared with that of East Africa. By observation we see that the long-term SST for all Julys from 1991 to 2020 in the Malacca Strait is about 5°C higher than that in the Gulf of Aden, even though the latitudes of the two areas are similar (see section S1.1 in the online supplemental material).

We use ArcGIS to aggregate the annual data into geospatially referenced grid cells. To measure long-term SST changes, we begin by aggregating the monthly mean SST data from 1970 to 2014 and creating a standard deviation for each month's mean temperature over time. We operationalize the SST measure as the number of standard deviations from the sample standard deviation.[4] To apply the SST scores to the oceans surrounding East Africa and the South China Sea, we design polygon shape files that include both regions according to the limits defined by the International Hydrographic Organization (1953). Next, we select all 1° × 1° grid cells that intersect with the polygon shape files and remove those occurring mostly over land. We then combine all of the individual grid cell temperature values into an aggregate monthly value for the two regions. Last, we take the average of each month of every year (2002–13 for East Africa and 1995–2007 for the South China Sea) and develop 12 monthly mean and standard deviation SST scores for each region. This process allows us to look at the monthly variation in SST controlling for seasonal variation from 2002 to 2013 for East Africa and from 1995 to 2007 for the South China Sea (see section S1.2 on the online supplemental material for a detailed explanation of the construction of our SST measure).

c. *Independent variable*

Our independent variable is the yearly total weight (in millions of tons) of all types of fish produced/captured. The time series for fish output measures total fish production at the time of each attack for all of the littoral countries in both regions reported to the Food and Agricultural Organization of the United Nations. We use the software "FishStatJ" to obtain the fish production data of the countries in the two regions under the workspace "FAO Global Fishery and Aquaculture Production Statistics." Littoral countries for East Africa are Comoros, Djibouti, Egypt, Eritrea, Kenya, Madagascar, Mauritius, Mozambique, Reunion, Seychelles, Somalia, South Africa,

[4] The No. of std dev = $(\mathrm{SST}_i - \overline{\mathrm{SST}})$/Sample std dev, $i = 2002, \ldots, 2013$.

Sudan, and Tanzania. Littoral areas for the South China Sea are Cambodia; China; Hong Kong, China; Indonesia; Macau, China; Malaysia; the Philippines; Singapore; Taiwan; Thailand; and Vietnam. Average annual fish output for the South China Sea (23 million tons) is more than 10 times the fish output for East Africa (just over 2 million tons).

d. *Control variables*

We include several controls that have been demonstrated by past research to significantly influence the risk of piracy. Previous studies indicate that the presence of enforcement agencies may deter pirates (Lindley 2016; Liss 2011; Rosenberg 2009). We therefore include a measure of whether the last attack was reported to the coastal authorities (yes = "1"; no = "0"). Table 1 shows that for both regions, about three-quarters of the time a previous attack was reported to coastal law enforcement authorities.

Prior research shows that private security guards can be an effective means of preventing crimes (Benson and Mast 2001; Cook and MacDonald 2011; MacDonald et al. 2016). We include a measure of whether private security guards were available during the attack (yes = "1"; no = "0"). The percentage of attacks involving private security guards is about 13 times as high in East Africa as in the South China Sea.

Prior research (Dinakar and Maurer 1999; Lindley 2016) suggests that poor domestic economic conditions may increase the incidence of maritime piracy. We therefore include an economic stress index that is computed as the sum of the yearly inflation and unemployment rates in each of the littoral countries in both regions.[5] This measure is approximately 9 times as high in East Africa as in the South China Sea.

Because the sheer volume of maritime traffic has been shown to be a predictor of piracy (Bensassi and Martínez-Zarzoso 2012; Fu et al. 2010; Martínez-Zarzoso and Bensassi 2013), we include a measure of regional trade as a proxy for the total number of ships passing through each region. We operationalize regional trade as the sum of exports plus imports from Asia–Europe, Oceania–Europe, Middle East–Europe, and East Africa–Europe for the East Africa region; and Asia–Europe and Asia–Middle East for the South China Sea region. According to Table 1, the proportion of trade that is regional is roughly 2 times as high in East Africa as in the South China Sea.

Research by Pristrom et al. (2016) and others (Dinakar and Maurer 1999; Psarros et al. 2011) shows that merchant ships are vulnerable piracy targets because they often pass at low speed and close to shore. To account for the possibility that the hazard of piracy will increase when the movement of merchant vessels across these two regions is higher, we use the dichotomous variable "merchant ship" to indicate whether the vessel type for each attack is a merchant ship (yes = "1"; no = "0"). Merchant ships are roughly 2 times as common for the East Africa region as they are for the South China Sea region.

Because prior research (Dugan et al. 2005; Holden 1986) finds evidence of contagion effects when illegal activities are successful, we use the temporal ordering of piracy attacks to construct a success density measure. This variable is calculated by taking the current and two previous piracy attacks and, calculating the probability of success divided by the number of days of the current piracy attack from the second previous piracy attack, weighted by 365 days.[6] On average this measure is about 2 times as high in the South China Sea as in East Africa.

As noted by Vagg (1998) and Hastings (2009), regions experiencing high levels of piracy frequently also suffer from more general lawlessness and corruption. According to these authors, fishers are more likely to resort to piracy when the decline in fish production is not compensated by the government. Therefore, we include a regional "rule of law index," "political stability index," and "corruption perception index" to control for the possibility that the strength of legal and political institutions significantly effects redistribution policies. As shown in Table 1, the regional "rule of law index" and the "political stability index" are much weaker in East Africa than in the South China Sea.

6. Methods

To quantify the effect of fish production—induced by the changes in sea surface temperature—on the changes in the risk of piracy attacks, we employ a two-stage instrumental variable regression approach. As noted earlier, we exploit the changes in sea surface temperature as an instrument for fish production. We use R Statistical Software, version 4.0.0, to perform all statistical analysis (R Core Team 2018).

Structural equation models (Bollen 1989; Weston and Gore 2006) are used to address unmeasured confounding in which the instrumental variable serves 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) argue that the classic use of instrumental variables in criminology research is for treatment effect estimation in randomized controlled trials (RCTs) or nonexperimental studies facing selection bias, simultaneity, and measurement error. Most criminology applications of instrumental variables to date (Apel et al. 2008; Kirk 2009; Levitt 1996; Spelman 2008; Tita et al. 2006) have been based on two-stage least squares estimation of structural equation models that are linear and specified for discrete or continuous outcomes. However, there are far fewer studies in criminology using instrumental variable methods to examine time-to-event issues. Recently, epidemiologists have sought to resolve the simultaneity and selection bias in time-to-event analysis by pioneering an instrumental variable approach for regression analysis in a survival context, using additive hazards models (Chan 2016; Li et al. 2015; Tchetgen et al. 2015). In this paper we follow a similar strategy, adapting the two-stage instrumental variable method proposed by Li et al. (2015).

[5] Following Tang and Lean (2009) we prefer this index because it controls for the effects of economic stress without adding multicollinearity between inflation and unemployment.

[6] The mathematical equation is P(success for current and two previous attempts)/[(event_date$_{\text{current}}$ − event_date$_{\text{second_previous}}$)/365].

Using the semiparametric additive hazards model conditional on the covariate $\mathbf{X}$, the hazard function of the survival time t satisfies

$$h(t;\mathbf{X}_{\text{Fish}}, \mathbf{X}_{\text{Controls}}, \mathbf{X}_u) = h_0(t) + \boldsymbol{\beta}_{\text{Fish}}\mathbf{X}_{\text{Fish}} + \boldsymbol{\beta}_o^{\text{T}}\mathbf{X}_{\text{Controls}} + \boldsymbol{\beta}_u^{\text{T}}\mathbf{X}_u, \quad (1)$$

where $\mathbf{X}_{\text{Fish}}$ is an endogenous variable for fish output, $\mathbf{X}_{\text{Controls}}$ are the vector of observed exogenous covariates, and $\mathbf{X}_u$ is a $\mathbf{q}$ matrix of unobserved explanatory variables that are correlated with $\mathbf{X}_{\text{Fish}}$. In the subsequent analysis, we assume the means of all covariates are centered at zero without loss of generality.

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

$$S(t;\mathbf{X}_{\text{Fish}}, \mathbf{X}_{\text{Controls}}) = S_0(t)\exp[-t(\boldsymbol{\beta}_{\text{Fish}}\mathbf{X}_{\text{Fish}} + \boldsymbol{\beta}_o^{\text{T}}\mathbf{X}_{\text{Controls}})] \times \int \exp(-t\boldsymbol{\beta}_u^{\text{T}}\mathbf{X}_u)\, dF(\mathbf{X}_u|\mathbf{X}_{\text{Controls}}). \quad (2)$$

Given that $\mathbf{X}_{\text{Fish}}$ is confounded by $\mathbf{X}_u$, the effect of $\mathbf{X}_{\text{Fish}}$ on the survival probability may still enter

$$\int \exp(-t\boldsymbol{\beta}_u^{\text{T}}\mathbf{X}_u)\, dF(\mathbf{X}_u|\mathbf{X}_{\text{Controls}}).$$

As a result, fitting the model

$$h(t;\mathbf{X}_{\text{Fish}}, \mathbf{X}_{\text{Controls}}) = h_0(t) + \boldsymbol{\gamma}_{\text{Fish}}\mathbf{X}_{\text{Fish}} + \boldsymbol{\gamma}_o^{\text{T}}\mathbf{X}_{\text{Controls}} \quad (3)$$

will lead to the estimator of $\tilde{\boldsymbol{\gamma}}_{\text{Fish}}$ being inconsistent for the parameter of interest $\boldsymbol{\beta}_{\text{Fish}}$ in (2).

We use the standard specification for the endogenous variable in instrumental variable estimation (Bollen 1989) to obtain a consistent estimator for $\boldsymbol{\beta}_{\text{Fish}}$:

$$\mathbf{X}_{\text{Fish}} = \boldsymbol{\alpha}_C + \boldsymbol{\alpha}_{\text{SST}}\mathbf{X}_{\text{SST}} + \boldsymbol{\alpha}_o^{\text{T}}\mathbf{X}_{\text{Controls}} + \boldsymbol{\alpha}_u^{\text{T}}\mathbf{X}_u + \boldsymbol{\varepsilon}, \quad (4)$$

where $\boldsymbol{\alpha}_C$ is the coefficient for the constant intercept, $\boldsymbol{\alpha}_{\text{SST}}$ is the coefficient for the instrumental variable; $\boldsymbol{\alpha}_0$ are the coefficients for the observed exogenous variables; and $\boldsymbol{\alpha}_u$ is the coefficient for the unobserved confounders; $\boldsymbol{\beta}_{\text{Fish}}$ can be estimated by coupling (3) and (4) according to the steps outlined in sections S2.1 and S2.2 of the online supplemental material.

7. Results

In Fig. 2a we show the fitted lines based on the predicted values extracted from the linear model of sea surface temperature (°C) against year by region, and 95% confidence interval for each predicted value. Note that we used the values for 12 months for each year. In Fig. 2b, the fitted lines based on the predicted values extracted from the linear model of sea surface temperature (°C) against year and region were broken down into months. Figure 2 shows that sea surface temperatures are consistently rising in both regions, and the baseline sea surface temperatures for the two regions are different.

Figure 3 compares the trends in our measure of sea surface temperature, measured as the number of standard deviations from the mean, over time for East Africa and the South China Sea. Visual inspection of the smoothed conditional means of our SST measure shows that our measure of SST (standard deviation from mean) is increasing in the two regions.

In Fig. 4, we show the smoothed conditional means of our SST measure and the fish production for the two regions. As previously noted, despite the fact that sea temperatures are steadily increasing in both regions, fish production during this period has gradually declined for East Africa but increased for the South China Sea. To determine the basic shape of the relationship between our SST measure and the log time (days) between successive piracy attacks, we used the B-spline function and plotted the results in Fig. 5. This estimator shows that for East Africa, SST and the hazard of being pirated were inversely related. In other words, the time between pirate attacks shortens as SST increases leading to a fall in fish production. However, for the South China Sea, increases in SST leads to longer time between piracy attacks. The findings remained valid after removing major SST outliers as shown in Fig. S1 in the online supplemental material.

Disaggregating each region into two areas (international water and territorial water), we observe that for East Africa, the relationship between our SST measure and the log time (days) between piracy attacks remains negative in both international and territorial water. For the South China Sea, we still find that increases in SST leads to longer time between piracy attacks in both international and territorial water (see Fig. 6). Figure S2 in the online supplemental material shows that these results remain consistent when major outliers are removed.

We next quantify the effect of variation in SST on the change in hazard of piracy in terms of fish output by instrumenting the endogenous variable fish output with the SST measure. In the top panel of Table 3, we show the relationship between the instrument (sea surface temperature; SST) and the endogenous variable (fish output) in East Africa. According to the estimates of the mean-centered first stage ordinary least squares (OLS) regression, the coefficient $\boldsymbol{\alpha}_{\text{SST}} \neq \mathbf{0}$ and is highly significant at the 0.1% level. Consistent with our predictions, the instrumental variable $\mathbf{X}_{\text{SST}}$ is *inversely* associated with $\mathbf{X}_{\text{Fish}}$, that is, the relationship between SST and fish production is strongly negative for East Africa. The results show that for every 1-unit increase in the standard deviation of SST, fish output decreases by 0.035 million tons.

In the top panel of Table 4, we again find that the coefficients $\boldsymbol{\alpha}_{\text{SST}} \neq \mathbf{0}$ and they are highly significant at the 0.1% level. Unlike in East Africa where SST and fish output production are inversely related, SST and fish output production are *positively* related in the South China Sea. For every 1-unit increase in the standard deviation of SST, fish output increases by 1.113 million tons for the South China Sea. Taken together, these results support our argument that SST is a suitable instrument for fish production in East Africa and the South China Sea.

The bottom panels in Tables 3 and 4 show the magnitude of the change in the hazard of piracy (i.e., average days until the next attack) for the second-stage semiparametric additive models in East Africa and the South China Sea, respectively.

Panel A

Panel B

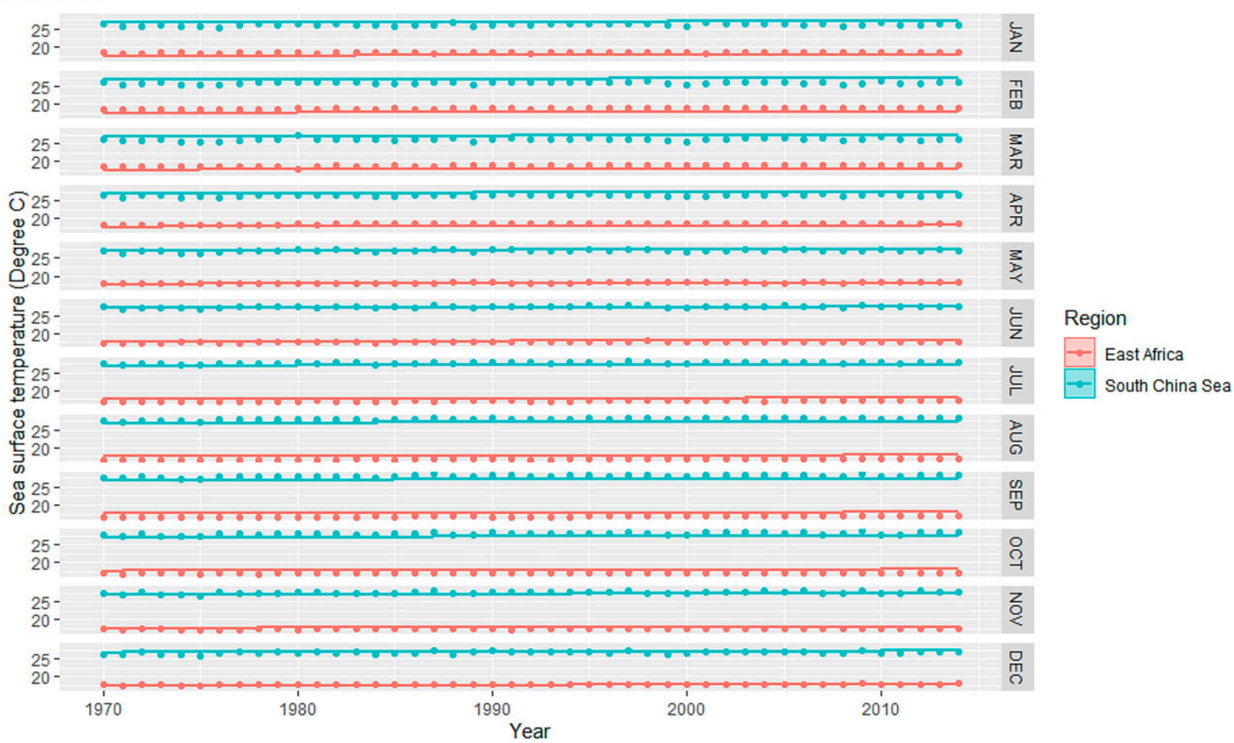

FIG. 2. Time path of sea surface temperature (°C) increase: (a) fitted lines based on the predicted values extracted from the linear model of sea surface temperature against year and region, along with 95% confidence interval for each predicted value, and (b) fitted lines based on the predicted values extracted from the linear model of sea surface temperature against year and region by month of the year.

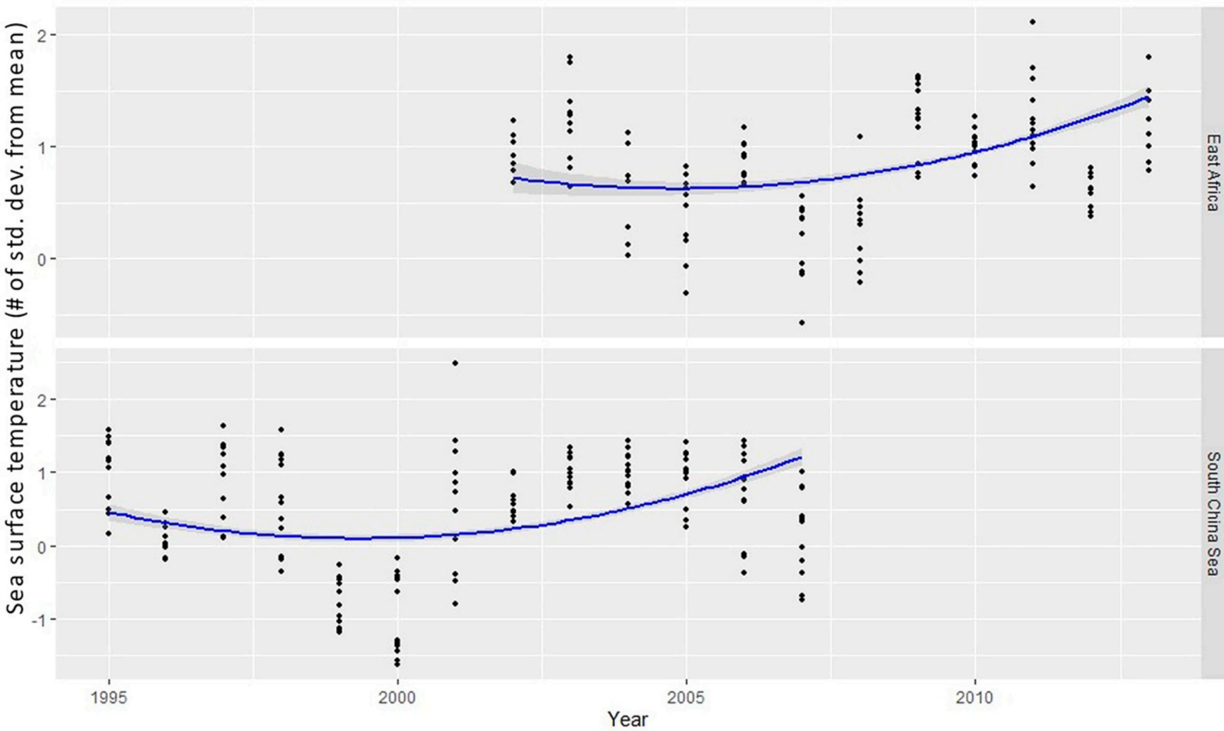

FIG. 3. Time path of sea surface temperature (No. of std dev from mean) increase. Shown are smoothed conditional means of sea surface temperature (No. of std dev from mean) against year for (top) East Africa and (bottom) the South China Sea. The functional form of the smoothed conditional mean is polynomial.

The exclusion restriction criteria are satisfied as we argued in section S2.2 of the online supplemental material. Because this is the second stage of an analysis based on using SST as an instrument for fish production, we are expecting the coefficients for SST to be negative and significant. We first estimate the unconditional model without including the controls and find that the coefficient for the instrument SST remains negative and significant for both regions.

For East Africa, the hazard of piracy increases when an increase in SST leads to a decrease in fish output, consistent with our expectation. According to the bottom panel of Table 3, an SST increase that leads to a decrease of fish output by 1 million tons increases the piracy hazard by 248%, 254%, 343% and 240% for models 1–4, respectively. As with the East Africa analysis, we next estimate the change in the hazard of piracy (i.e., average days until the next attack) for a second-stage semiparametric additive model in the South China Sea. Consistent with our expectations, the hazard of piracy decreases when an increase in SST leads to an increase in fish output. According to the bottom panel of Table 4, an SST increase that leads to a decrease of fish output by 1 million tons increases the piracy hazard by 1.5%, 2% and 2.3% for models 1–3, respectively. In additional analysis (see Fig. S3 in the online supplemental material) we also find important differences between the two regions in terms of whether attacks happened in international, territorial, or port areas. For East Africa, the change in the hazard of piracy is the largest in international water, followed by territorial water and port areas. For the South China Sea, the results are reversed with the largest changes in port and territorial waters and negligible changes in international waters. These results closely follow the location of piracy attacks shown above in Fig. 1b, many piracy attacks in East Africa occur far into the ocean, whereas most in the South China Sea take place relatively close to land. To ensure that our estimates are reliable, we show the outcomes for three postestimation tests at the bottom of Tables 3 and 4. The results of the supremum test of significance coefficient are significant across both regions and in all model specifications. This means that the functional forms of the covariate are well specified.

We next examine the effect of changes in SST on whether piracy attacks were successful (i.e., pirates managed to hijack the ship, kidnap the crew, board the vessel, or escape with valuables). Our instrumental variable probit regression results provide significant empirical support for our central argument—climate change has had opposite effects on fish production in the two regions and is associated with more successful piracy attacks in East Africa and less successful attacks in the South China Sea (see Table 5). According to the first-stage fitted results given in Table 5, the relationship between SST and piracy remains strongly negative for East Africa and strongly positive for the South China Sea. Every 1-unit increase in the standard deviation of SST is associated with a decrease of 0.038 million tons of fish output in East Africa and an increase of 0.988 million tons in the

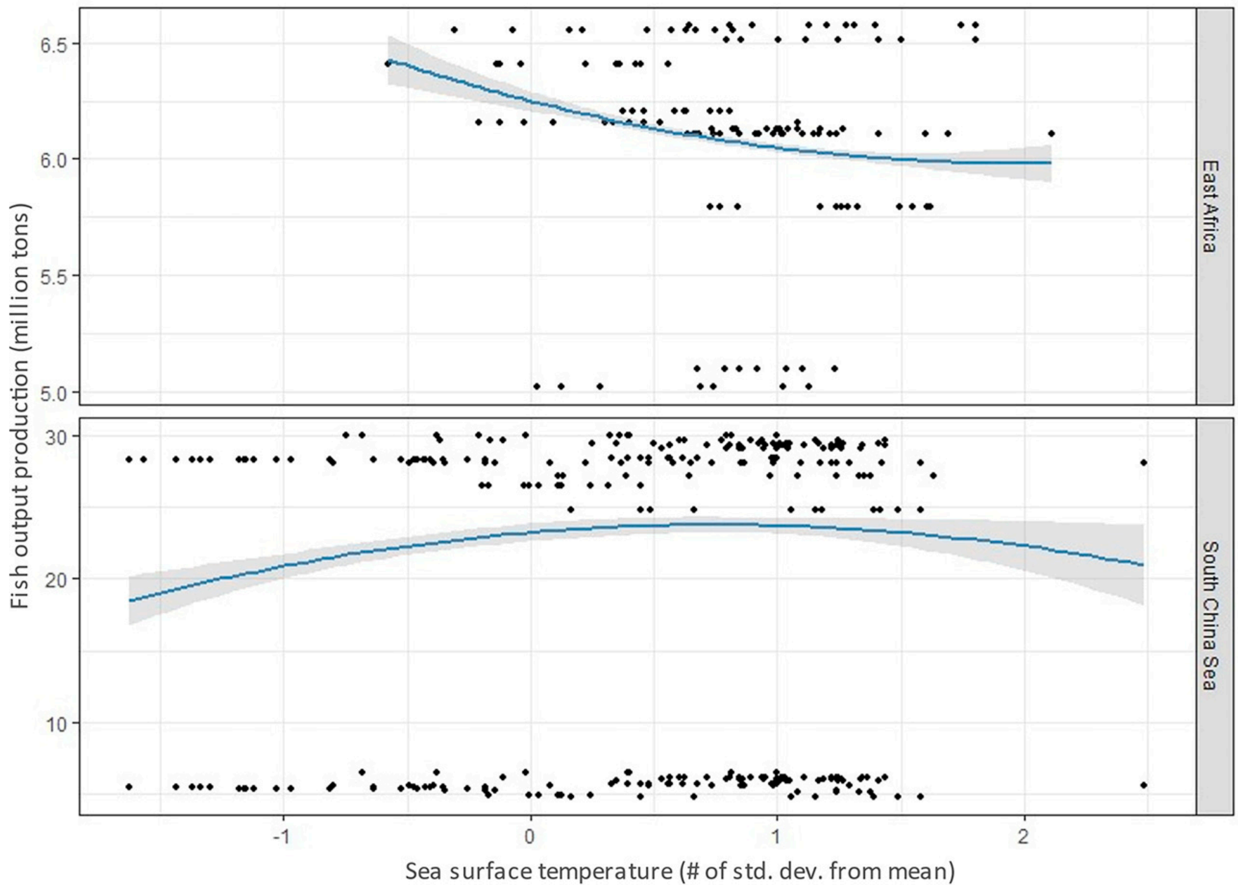

FIG. 4. Sea surface temperature (No. of std dev from mean) effect on fish output production (million tons) by region. Shown are the smoothed conditional means of fish output production (million tons) against sea surface temperature (No. of std dev from mean) and 95% confidence intervals. The functional form of the smoothed conditional mean is polynomial.

South China Sea. We instrumented fish production with SST in the second stage of the instrumental variable probit regression. The coefficient estimates for East Africa in Table 5 shows that an SST increase that leads to decreases of fish output increases the success of piracy attacks, controlling for the set of covariates consistent with model 1 in Table 3. For the South China Sea, the coefficient estimate suggests that an SST increase that leads to an increase in fish catch production is associated with a decrease in the success of piracy attacks, controlling for the set of covariates consistent with model 1 in Table 4. These findings are consistent with our predictions. We perform postestimation tests to maximize confidence in the results. First, we perform a Wald test of the exogeneity of the instrumented variable. We reject the null hypothesis of no endogeneity and conclude that the instrumental variable probit approach is more appropriate than a regular probit for both regions. We next perform weak-instrument robust tests and confidence sets for instrumental variable probit. The Anderson–Rubin test statistics show that our models for both regions are well specified and that the exogeneity assumption is generally satisfied under the 0.05 significance level.

To enhance confidence in our results, we estimate three models that just connect piracy with warmer sea surface temperatures. The findings suggest that increases in SST in East Africa are associated with more frequent but less successful piracy attacks. In the South China Sea, increases in SST lead to less frequent but more successful attacks (refer to section S2.3 in the online supplemental material).

8. Discussion and conclusions

In this paper, we test the possibility that climate change affects participation in maritime piracy differently, depending on the specific ways that it impacts regional fish production. Our research focuses on East Africa and the South China Sea, two regions that have had high rates of maritime piracy in recent years. Consistent with prior research (Huang et al. 2015), our results show slow but steady increases in sea temperature in the oceans surrounding both regions. However, we find that these changes have been associated with declining fish production in the oceans surrounding East Africa but increasing fish production in the South China Sea. We argued above that rational choice arguments are well suited to understanding maritime piracy. Case studies of areas that depend on fishing suggest that individuals move back and forth between fishing and potentially lucrative illegal activities depending on local economic conditions. Moreover, those who

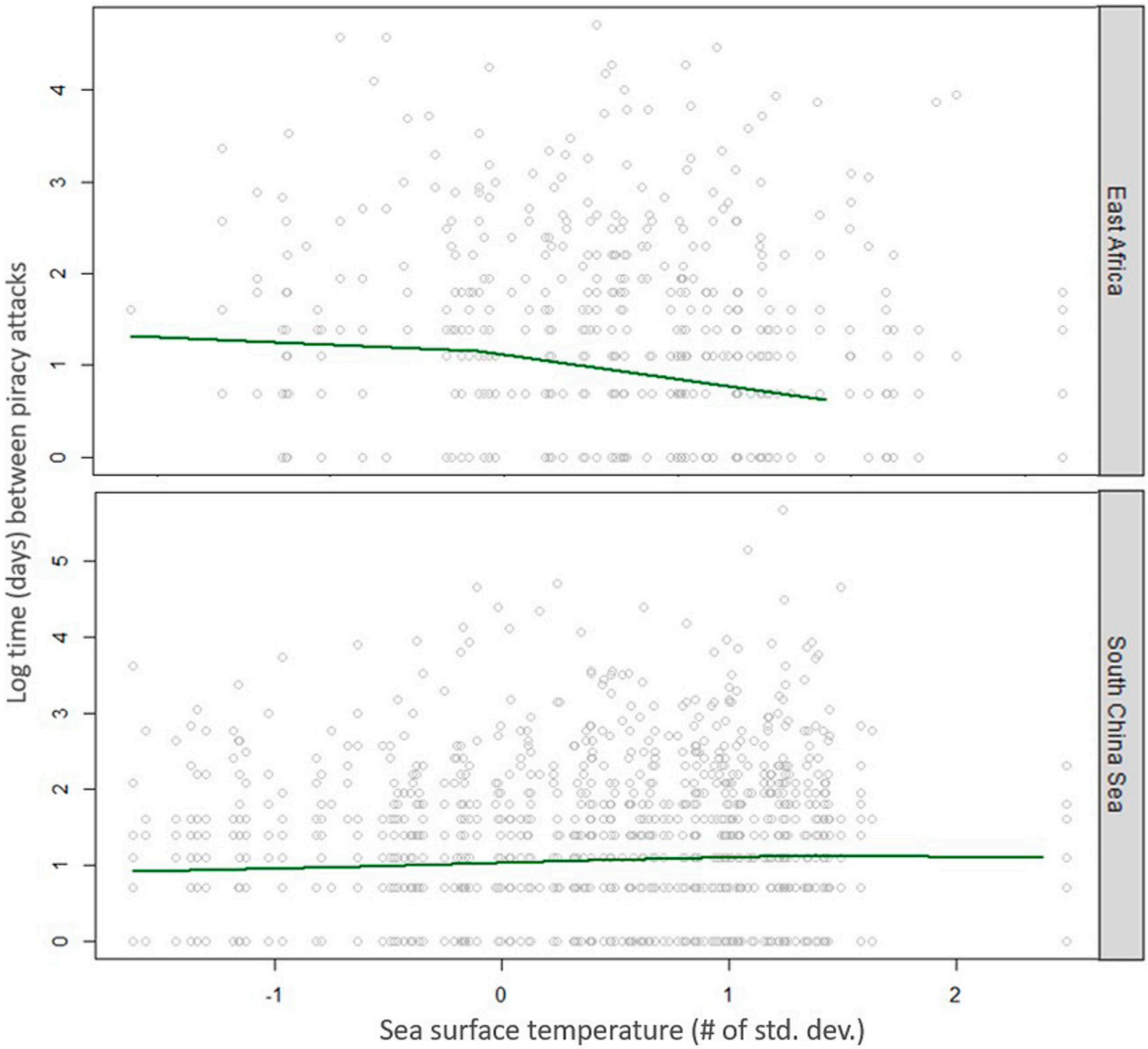

FIG. 5. Sea surface temperature (No. of std dev from mean) effect on the risk of piracy attacks by region. Shown are the B-spline functions of degree 3 for (top) East Africa and (bottom) the South China Sea.

earn a living by fishing have a unique set of specialized skills that make them more likely than others to be successful maritime pirates. Our findings contribute to the stock of scientific knowledge about security implications of climate change (von Uexkull and Buhaug 2021).

Despite the positive findings, some concerns about International Maritime Organization (IMO) data quality are noted. While we agree that the IMO data possess many desirable characteristics for conducting cross-regional comparisons of maritime piracy risks, we also acknowledge that the data are likely limited by self-selection in reporting and underreporting. Relative to unsuccessful attacks, successful attacks may be more likely to be reported because ship owners must make official reports to substantiate insurance claims. For the problem of underreporting, merchant ship owners may be discouraged from filing official reports because the process is expensive and the time needed for investigation is often long. Incentives for reporting are further diminished because evidence of being attacked may increase future insurance premiums. Reporting may also be reduced because of fears that confirmed attacks will tarnish the reputation of the carrier and customers will no longer perceive it to be safe and reliable. However, it is worth noting that underreporting is a general problem with most property crimes and not specific to maritime piracy.

The most fundamental premise of the rational choice perspective is that different types of behavior will be shaped by the costs and benefits of that behavior. Our data allowed us to test this premise in a very specific way by looking at the impact of fish production on piracy in one region with

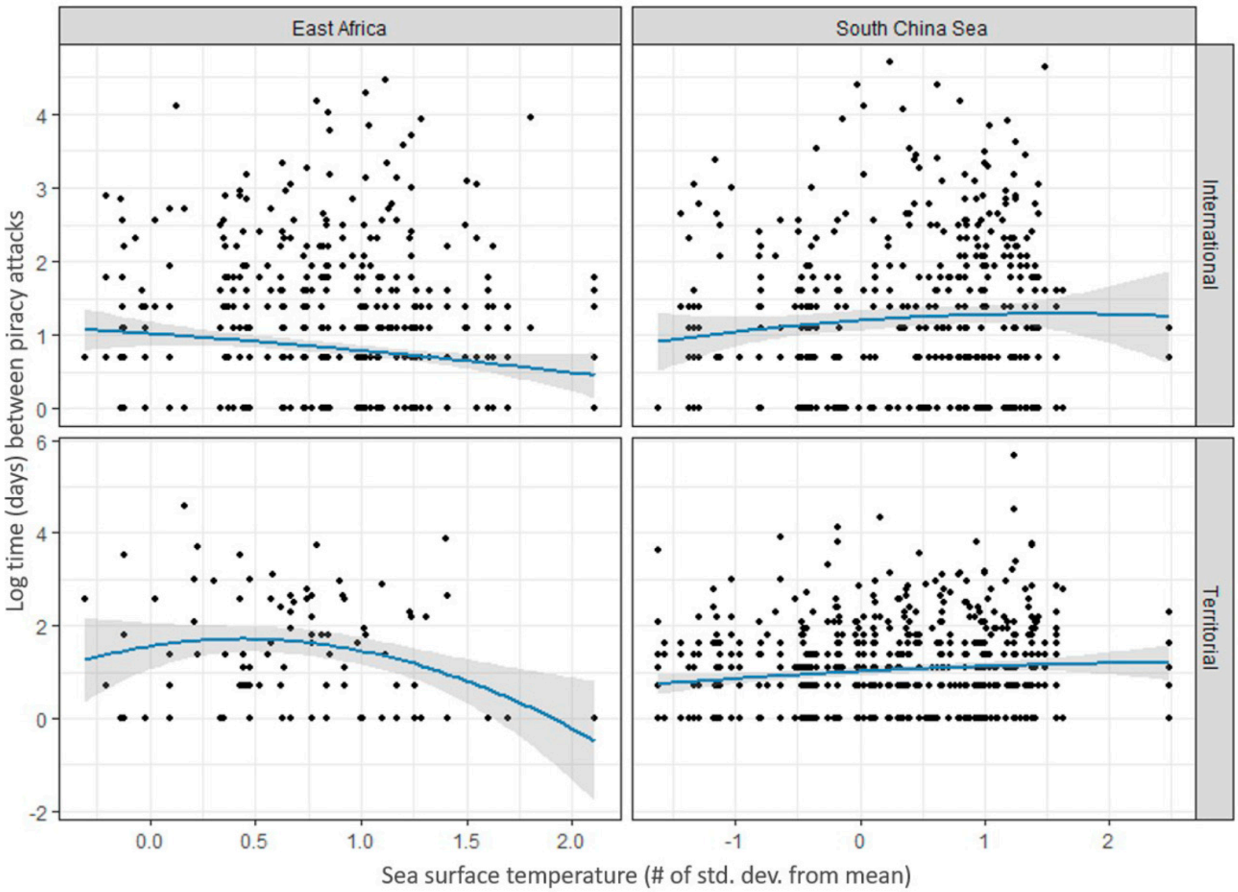

FIG. 6. Sea surface temperature (No. of std dev from mean) effect on log time (days) between piracy attacks by region and area. Shown are the smoothed conditional means of fish output production (million tons) against sea surface temperature (No. of std dev from mean), and 95% confidence intervals.

decreasing fish production and another region with increasing fish production. In support of the cost–benefit principle, we find that piracy increased when fish production declined and dropped when fish production grew. Moreover, we are able to demonstrate the combined effects of sea temperature as an instrument on fish production and the effects of fish production on the instantaneous risk of being pirated in two world regions with high rates of piracy.

Our research extends the generalizability of Becker (1968) by applying his perspective to a type of offense that has rarely been studied from a rational choice perspective. With few exceptions (Ehrlich 1973; Graff Zivin and Neidell 2014), prior research informed by rational choice theory has not focused on the impact of shifting opportunities on crime. Our research suggests that we may get more useful estimates of crime by considering the decision to engage not as a simple dichotomy but as a time allocation problem that may evolve depending on situational characteristics making crime more or less profitable.

This last point, that criminal behavior is rarely a simple dichotomy, has important theoretical implications. Our findings provide support for the rational-choice perspective by showing the direct impact of shifting economic opportunities on crime. Using a novel approach that was recently introduced in public health research, we find that there is statistically significant evidence to support the conclusion that the economic conditions faced by fisherman influence the instantaneous risk of piracy attacks in East Africa and the South China Sea. Our results are consistent with the idea that normally law-abiding fishers are more likely to turn to maritime piracy when the economic conditions they face make it more attractive. Conversely, our results also show that fishers are more likely to turn away from piracy when legitimate economic conditions are more favorable. While our results apply to the specific case of maritime piracy, the idea that criminal behavior is rarely a stark contrast between criminal and noncriminal action but rather a moving calculus depending on the costs and rewards of criminal and noncriminal behavior may have great generalizability.

In a period in which climate change is one of the most important challenges facing the world (Nerini et al. 2019; Smith et al. 2018), criminologists have thus far produced relatively little research on connections between various consequences of climate change and specific types of crime. This may be

TABLE 3. Semiparametric additive hazard model of piracy attacks in East Africa. Shown are the estimates from the two-stage instrumental variable models unconditional and conditional on the covariates. The means of all covariates are centered at zero without loss of generality. The table-head categories apply to stage two, only. The dagger and one, two, and three asterisks denote significance level p of ≤ 0.1, ≤ 0.05, ≤ 0.01, and ≤ 0.001, respectively (all two-tailed tests). Standard errors are given in parentheses.

	Unconditional	Model 1	Model 2	Model 3	Model 4
			Stage one: Fish production (million tons)		
Sea surface temperature (No. of std dev)			Coef = −0.035*** (0.005)		
Intercept			Coef = 2.034*** (0.005)		
			Stage two: Change in hazard of piracy attacks		
Instrument					
Sea surface temperature (No. of std dev)	−2.05*** (0.416)	−2.48*** (0.371)	−2.54*** (0.379)	−3.43*** (0.379)	−2.4*** (0.379)
Controls					
Private security guard		−0.018 (0.019)	−0.016 (0.019)	−0.004 (0.021)	0.036 (0.021)
Economic stress index		0.001 (0.000)	0.001 (0.000)	−0.003*** (0.001)	0.004*** (0.000)
Regional trade		0.028* (0.012)	0.017* (0.014)	0.075* (0.036)	−0.014 (0.014)
Merchant ship		−0.010 (0.015)	−0.007 (0.015)	−0.024 (0.015)	−0.012 (0.015)
Success density		0.003*** (0)	0.003*** (0)	0.003*** (0.001)	0.003*** (0.001)
Last reported		0.048* (0.024)	0.052* (0.024)	0.0595* (0.026)	0.056* (0.025)
Political stability index			0.035 (0.125)		
Rule of law				1.54*** (0.601)	
Corruption perceptions index					−0.122*** (0.009)
Test for nonsignificant effects					
Supremum test of significance	5.56***	6.75***	5.97***	4.58***	6.27***
Sample size	1049	1049	1049	1049	1049

explained in part because of the common assumption that climate change unfolds very gradually over long periods of time, whereas crime measures often fluctuate over much shorter time periods (Guttman 1989; Lynch 2020). However, the results presented here suggest that this assumption may not be accurate with regard to the effects of sea temperature on maritime piracy. Our results show strong connections between changes in sea temperature and piracy through fish production over a little more than a decade. Moreover, while we did not explore these issues in the current project, there may be "tipping points" in the relationship between sea temperature and piracy beyond which maritime piracy becomes far more common.

In international organizations such as the European Union and the United Nations Security Council, policy responses to the security implications of climate change are being developed (Fetzek and van Schaik 2018). These initiatives are the impetus for enhancing awareness and aim to seek common ground for industries and individuals whose livelihoods are most affected by climate change to develop sustainable and

TABLE 4. As in Table 3, but in the South China Sea.

	Unconditional	Model 1	Model 2	Model 3
		Stage one: Fish production (million tons)		
Sea surface temperature (No. of std dev)		Coef = 1.113*** (0.266)		
Intercept		Coef = 22.552*** (0.244)		
		Stage two: Change in hazard of piracy attacks		
Instrument				
Sea surface temperature (std dev)	−0.016** (0.006)	−0.015** (0.005)	−0.02* (0.008)	−0.023*** (0.006)
Controls				
Private security guard		−0.031 (0.028)	−0.032 (0.03)	−0.033 (0.029)
Economic stress index		−0.002† (0.001)	−0.007** (0.002)	−0.009*** (0.002)
Regional trade		−0.002 (0.015)	−0.002 (0.029)	−0.011 (0.018)
Merchant ship		−0.007 (0.009)	0.002 (0.011)	0.001 (0.011)
Success density		0.003*** (0)	0.003*** (0)	0.003*** (0)
Last reported		0.036** (0.011)	0.056** (0.019)	0.057** (0.018)
Political stability index			−0.008 (0.149)	
Rule of law				0.109 (0.136)
Test for nonsignificant effects				
Supremum test of significance	5.35***	4.46***	3.34***	4.96***
Sample size	1830	1830	1306	1306

TABLE 5. Two-stage instrumental variable probit regression predicting success of piracy attacks by region. We coded an attack as successful when pirates managed to hijack the ship, kidnap the crew, board the vessel, or escape with valuables. The means of all covariates are centered at zero without loss of generality. One, two, and three asterisks denote significance level p of ≤ 0.05, ≤ 0.01, and ≤ 0.001, respectively (all two-tailed tests). Standard errors are given in parentheses.

	East Africa	South China Sea
Stage one: fish production (million tons)		
Sea surface temperature (No. of std dev)	-0.038^{***} (0.005)	0.988^{***} (0.279)
Intercept	2.036^{***} (0.006)	22.593^{***} (0.245)
Controls (model 1)	Yes	Yes
Stage two: Success of piracy attacks		
Instrumented: sea surface temperature (No. of std dev)		
Fish production (million tons)	5.463^{*} (1.918)	0.149^{**} (0.054)
Intercept	-11.309^{*} (3.811)	-3.101^{**} (1.243)
Controls (model 1)	Yes	Yes
Weak-instrument robust-test statistic		
Anderson–Rubin	5.35^{*}	15.8^{***}
Wald	4.82^{*}	7.62^{**}

innovative solutions. Ultimately, their success relies on valid empirical evidence about connections between climate change and fish production. If our arguments are correct, and sea temperatures continue to rise into the foreseeable future, the struggle against piracy in East Africa will become increasingly difficult. Fishers who face declining fish production may be expected to allocate more of their time to piracy as a rational economic strategy. To policy makers, the question then becomes how to develop sustainable solutions to decouple the link between legitimate (fishing) and illegitimate (pirating) activities? Can some of the monetary resources allocated to regional and international efforts to combat piracy be redirected instead toward breaking the connection between fish output and piracy? What are some of the feasible ways to diversify a fisherman's income profile? Achieving greater income diversification may require maritime countries or international agencies to do more to provide subsidies and job training to fishers in times of declining fish production. One way to realize these outcomes is to redirect part of the income from fishing licenses granted to foreign vessels to compensate local fishers.

Maritime countries and international agencies should continue to explore what more can be done to break the connection between fish availability and the risk of piracy, and search for policies that enhance the sustainability of the fishing sector and make it less vulnerable to climate change. Our findings suggest that as climate change continues, its impact on crime will likely be complex, with increases and decreases depending on the specific situational context and the rational choices these changing conditions generate.

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Data availability statement. This paper makes use of publicly available data on maritime piracy from the International Maritime Organization Global Information Shipping System database (https://gisis.imo.org/Public/Default.aspx). Research products from this project will be archived at the Digital Repository at the University of Maryland (DRUM) unless a more appropriate facility can be identified. DRUM is a long-term, open-access repository managed and maintained by the University of Maryland Libraries. Researchers and the general public can download data and code files, associated metadata and documentation, and any guidelines for reuse. All records in DRUM are assigned a persistent DOI to support consistent discovery and citation. The project description will be automatically indexed in Google and Google Scholar to support global discovery. Whenever possible, digital curation specialists in the University Libraries work with researchers to document and format materials for long-term access. A URL containing data for replication and the R replication code will be made available upon request.

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