The Welfare Cost of Lawlessness: Evidence from Somali Piracy*

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Abstract

This paper estimates the effect of piracy attacks on shipping costs using a unique data set on shipping contracts in the dry bulk market. We look at shipping routes whose shortest path exposes them to piracy attacks and find that the increase in attacks in 2008 lead to around a eight to thirteen percent increase in shipping costs. We use this estimate to get a sense of the welfare loss imposed by piracy. Depending on what is included, we estimate that generating around 120 USD million of revenue for pirates in the Somalia area led to a welfare loss of anywhere between 0.9 and 3.6 USD billion. Even at the lower bound, therefore, piracy is an expensive way of making transfers.

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1 Introduction

For centuries, piracy has posed a threat to ocean-going trade.[1] In essence, it is organized private predation which thrives in locations in which law and order is weak, either because particular states provide safe haven or due to poor international cooperation. And it has repercussions for worldwide trade.

However, despite the long-standing importance of piracy, little is known about its economic costs.[2] The issue has been brought into sharp relief by the upsurge of piracy in the Gulf of Aden which poses a threat to one of the world's busiest shipping routes. Frequently attributed to the collapse of effective authority in Somalia, it has provoked an international response. However, the threat to shipping remains.

This paper does two main things. First, we match data on piracy attacks in the two most active pirate areas (Somalia and Indonesia) to data on around 24,000 shipping contracts. We do this by constructing the closest navigable sea distance between each origin and destination port for which a ship has been chartered. This allows us to exploit the monthly time-series variation in the frequency of piracy attacks in our two piracy areas and to estimate how much an upsurge in piracy raises shipping costs. Second, we use these estimates to examine the welfare cost of Somali piracy.

We estimate that shipping costs for dry bulk goods rose by around 8% when pirate activity increased in Somalia. This varies with changes in pirate activity induced by seasonal changes in weather. Our estimates suggest that it is around 14% cheaper to charter ships through the Gulf of Aden during the months with lower seasonal pirate activity (December-February and June-September). Moreover, this seasonal pattern in shipping prices is absent prior to the upsurge in pirate activity in the region during 2008. There is little robust evidence of any effects of piracy attacks on shipping that passes through the Indonesia region where piracy attacks are less prevalent and hijackings less common during the period of our data.

The extra shipping costs that we uncover are mostly due to higher insurance costs and the increased security measures that are needed to repel

[1]For example, North (1968) argues that a decline in piracy from 1600 to 1850 accounts for a significant proportion of the observed productivity increases in transatlantic shipping in this period.

[2]Bensassi and Martínez-Zarzoso (2011) study the impact of piracy in the Strait of Malacca on trade costs. Most cited numbers are from One Earth Future Foundation (2010, 2011).

pirate attacks. These constitute a welfare cost to the extent that labor and resources are allocated from productive tasks towards protection. We develop a model to compare the extraction of resources through pirate attacks to a tax on shipping which finances an equivalent transfer. This allows us to calculate the welfare loss caused by piracy. Our central estimate suggests that the resource costs incurred in transferring around 120 million USD annually to Somali pirates is well in excess of 630 million USD. This confirms the general point that predation is a lot more costly as a form of extraction than taxation. The former is a form of anarchy while the latter requires a state that exercises a monopoly of force within a territory.

The paper belongs to a wider literature on the value of establishing the rule of law and its role in securing trade and investment.[3] A traditional problem in weakly-institutionalized environments is that bringing goods to market is subject to predation and theft. The consequences of the failure to establish and enforce property rights is a core theme in the development literature, for example, Acemoglu, Johnson and Robinson (2001). The large literature on the economic costs of corruption, another form of widely observed extra-legal transfers is also relevant.[4]

Piracy has always posed a particular issue because of the difficulty of securing international agreement over whose responsibility it is to deal with the problem and how the costs are shared. Private solutions to increase security such as carrying guards aboard ships are inherently less efficient compared to dealing with the public good of security for all.[5] Our calculation of the welfare cost gives a sense of the magnitude of this benefit and we discuss why this is so high compared to tax-based redistribution.

Insecurity due to piracy causes a rise in shipping costs which are an important part of total trade costs. In this respect, our paper relates to studies of the consequences of trade costs for trade patterns.[6] Feyrer (2009) relates in his study of the Suez Canal closure 1967-1975. Our welfare calculations build on his findings

The remainder of the paper is organized as follows. In the next section, we discuss the background to both our piracy and shipping cost data. Sec-

[3] See Dixit (2004) and Rose-Ackerman (2010) for excellent overviews and Olken and Barron (2009) for a recent contribution using data from Indonesia.

[4] For a survey and overview, see Olken and Pande (2011).

[5] See Bandiera (2003) for a similar argument.

[6] For a review see Behar and Venables (2011). See Donaldson (2010) for a recent study of the impact of a change in trade costs due to the advent of railroads in India.

tion three presents our estimation procedure and discusses the results while section four provides a framework for thinking about the welfare loss and uses this, along with our estimates, to develop estimates of the welfare loss from piracy. Concluding comments are in section five.

2 Background and Data

In this section we discuss our data on piracy and shipping costs. We present potential channels for piracy to affect these costs. We also discuss how susceptibility to piracy is matched to shipping routes.

2.1 Piracy Data

Modern piracy is an organized and sophisticated crime.[7] Our data on such attacks comes from the ICC International Maritime Bureau (IMB) annual reports which provide the exact position of the attack, details on the ship and its status (anchored or steaming) and the type of attack (attempted, boarded, fired upon, hijacked).[8]

We coded attacks by their geo-code and focus on two main areas where piracy is most prevalent for the period 2003 to 2010. Both of these areas are shown in Figure 1. The first is the Somalia area, which we define geographically as the rectangle spanned by the coordinates S11, E38.4 and N18.3, E74.7. The second area is the broader Indonesia area, which includes the Strait of Malacca. We define this area through the coordinates S10, E95.8 and N7.4, E120.7.

The red dots represent the locations of the piracy attacks. We focus on these areas because we believe that there are common factors driving piracy attacks within these zones, i.e. if pirates attack in some part of the area, it is informative about the likelihood of an attack elsewhere within it. For Somali pirates this is well documented. Given that the Indonesia area is smaller, our assumption does not seem unrealistic there either. Figure 1 also depicts two more geographically narrower areas – the Gulf of Aden and the Strait of Malacca, which we use as a robustness check on our main results below.

There is considerable variation in the intensity of attacks over time. Figure 2 summarizes the time dimension of attacks in both Somalia (left)

[7] See Leeson (2007) for a discussion of the organization of piracy in history.

[8] We discuss our data in the appendix A. Table A1 provides summary statistics.

and Indonesia (right). Piracy in Indonesia has been the object of a longer-standing international effort to police the area by the governments of Singapore, Malaysia and Indonesia. Figure 2 shows a distinct shift in the amount of attacks in 2005. Today, the problem is deemed to be largely well-contained.

We attribute the main time series variation in piracy attacks to variation in law and order both on the high seas and surrounding area. In the case of Indonesia the main shift seems to be due to the strength of cooperative interventions by Singapore, Malaysia and Indonesia following three-way talks in September 2005. In the case of Somalia, the break down of the state of Somalia which made it infeasible for the local government to control attacks happened around May 2008, when, due to a fiscal crisis in the Puntland province, the provincial government stopped paying wages to the police.

Table 1 summarizes the data around the date that the Somalia area was declared a war risk area by the maritime insurance industry (May 2008). The average number of attacks increased from 2.8 attacks per month before that date to 17.1 attacks per month from May 2008 onwards. Pirates initially masqueraded as coast guards protecting Somali territorial waters from illegal fishing. This cloaked a build up of organized violence. According to Hansen (2009), a key trigger for the upsurge in violence was when the Puntland government in Somalia decided, due to a crisis in the public finances, that it could no longer afford to pay the police. Thus, the primary reason for intensification was the break down in law and order in Somalia which made it increasingly feasible for pirates to operate without sanction.

In addition, wind conditions play a crucial role affecting the seasonality in attacks. Evidence for the Somali region suggests that pirate vessels there are vulnerable to weather conditions. Most of the attacks are carried out using small vessels, known as "skiffs". These are typically between $7-10$ meters long and at most two meters wide with a low freeboard. This renders them particularly vulnerable to wind and waves. The summary in Table 1 illustrates the resulting seasonal pattern. The post May 2008 column features a strikingly low piracy risk in the Monsoon months of July and August, for example. In these months piracy attacks are indistinguishable from the pre May 2008 levels. The calm spring period is the most dangerous time with over 30 attacks in March and April. We discuss the close link between this seasonal pattern in attacks and wind speeds in appendix A.3.

2.2 Shipping Cost Data

Our shipping cost data comes from the web-site of N. Cotzias Shipping Consultants which provides monthly reports on the time charter market for the period November 2002 until December 2010.[9] The data is comprised of 33,529 individual charters in the dry bulk cargo segment of the market. These are ships that transport primary commodities such as iron ore or agricultural products such as grain. These types of vessels constitute approximately one third of the tonnage of the global shipping fleet. Short term chartering agreements are typical for bulk carrier ships, due to the volatile nature of commodity markets. Since the starting point for these charter agreements are previous agreements ('last done'), shipowners and charterers take an active interest in reports of recent transactions.[10] The individual time charter agreements are also used to construct general shipping indices such as the Baltic Exchange Dry Index (BDI). Thus our data-set provides a window onto the wider shipping market.

In a time charter agreement the shipowner places his ship, with crew and equipment, at the disposal of the charterer and bears the costs of keeping the ship operational. The charterer pays a daily charter rate and decides the type and quantity of cargo to be carried and the ports of loading and discharging. The charterer is also responsible for paying bunkers (fuel) and costs like port charges including the payments due, for example, for using the Suez Canal. The fact that time charter rates are provided on a daily basis makes them comparable across contracts of differing length.

The summaries made available on the web-site provide, among other information, the name of the ship, its deadweight tonnage (DWT) - a measure of ship size, the year it was built, the port or country of origin and the port or country of destination. From this information we construct our measure of shipping cost - the rate per day per DWT. We also use the origin and destination to assign the ship's voyage to countries (see appendix A.4). Our data set contains information on around 1600 distinct shipping routes. Most of the charters are from Asia with China making up the bulk of origin and destination locations.

[9] In early 2011, Cotzias merged with Intermodial (www.intermodal.gr). As of 25th July 2012, the Cotzias data was available on `http://www.goo.gl/g5d0c`.

[10] See Stopford (2009) for a detailed discussion of the time charter market.

2.3 Piracy Risks and Shipping Costs

There have been a number of costly private responses to the piracy threat. A variety of insurance arrangements have emerged to cover piracy risks with higher premia being paid to travel in areas deemed to be at risk. Ships increasingly carry armed guards and other preventive measures (mostly modifications to ship hulls) have become "best practice" which makes them relevant for insurance purposes.[11]

The costs to the shipping industry can be decomposed into five main categories: (i) damage to vessels (ii) loss of hire and delay to cargo delivery while a ship is held to ransom (iii) costs of defensive measures (iv) cost of ransoms and negotiators fees paid when a crew is kidnapped or a vessel is held (v) re-routing of vessels to avoid areas at risk. We discuss these cost factors in detail in Appendix C. Ship owners typically buy insurance to cover themselves against a number of these costs with insurance costs being sensitive to developments in the number of piracy attacks. Throughout the paper we assume a competitive insurance industry along with competitive shipping markets.

Our window on measuring costs is through shipping contracts whose prices adjust to reflect the above costs to the extent that they are borne by the ship owner and shifted to the charterer. This is not unrealistic. The association of independent tanker owners, for example, provides model clauses for chartering agreements with regard to piracy risks, stating that:[12]

> "Charterers shall indemnify Owners against all liabilities costs and expenses arising out of actual or threatened acts of piracy or any preventive or other measures taken by Owners [...], including but not limited to additional insurance premiums, additional crew costs and costs of security personnel or equipment."

Hence, there are good reasons for believing that the lion's share of these costs ultimately falls on charterers who compensate ship owners in the form of higher charter prices. Below, we will discuss the sensitivity of our welfare estimates regarding the division of these costs.

[11] Best Practice manuals are published and updated regularly by the shipping industry. See `http://www.goo.gl/zL1Ut`, accessed on 10.04.2012.

[12] Refer to `http://www.goo.gl/yShgs`, accessed on 10.04.2012.

2.4 Identifying Exposure to Piracy Risks

We assign a risk of exposure to piracy attacks to each shipping route. We do this by using the information on the origin and destination of the shipping contract. For example, a vessel with a destination in Germany and an origin in China is quite likely to travel through both the Somalia and Indonesia area. However, there are some cases where it is not entirely clear whether the vessel would travel on a Pacific route or an Indian Ocean and Atlantic route using the Suez canal.

In assigning piracy risk, we therefore employ a path algorithm to obtain an automatic coding of a route.[13] We are then able to see whether the shortest sea route passes though the piracy areas that we study. If it does, we will suppose that the shipping contract is subject to a piracy risk based on the forecast number of attacks in the relevant region.

Figure 3 provides a bird's-eye view of the constructed trade-routes for the areas around Somalia. Thicker lines indicate more charter agreements on that trade lane. The bottom right of figure 3 illustrates the bulk trade network allocated to port of Surabaya (Indonesia). Overall, we observe around 7,100 charters for routes going through the Somalia area and 10,600 charters through the Indonesia area.

This approach means that we are only able to assign an intention to treat (ITT) rather than the treatment itself. It is, for example, possible that some ships were re-routing around the Cape of Good Hope to avoid exposure to piracy risks. We check for this in the results section and find no evidence for changes in either the extent of traffic through the Suez Canal due to piracy or its composition. Assigning intention to treat based on different routes makes our results even stronger. This supports the view of other commentators, such as One Earth Future (2011), that re-routing around the Cape is not important.

3 The Effect of Piracy on Shipping Costs

We now formally present a model of piracy attacks and an empirical model that we then proceed to estimate. We also show some robustness checks and some extended results.

[13] Details are discussed in the appendix A.4.

3.1 A Model of Piracy Attacks

To motivate the time-variation in piracy attacks, consider the following simple theoretical model. Suppose that in region r, there are M_r active pirate ships and that in each period each pirate receives an opportunity to hijack a ship where V_{irt} is the benefit and c_{irt} is the cost.[14] Pirate i in region r at date t will launch an attack if the expected benefit exceeds the cost:

$$\xi_{rt} V_{irt} \geq c_{irt}$$

where ξ_{rt} is the region specific success probability, V_{irt} is the value of a successful attack and c_{irt} is the cost. We allow the success probability, ξ_{rt}, to depend on climatic conditions and the law and order situation in the region, e.g. whether piracy attacks are policed and there is a safe haven available in which to demand a ransom.

A key parameter is the cost-benefit ratio $\rho_{irt} = c_{irt}/V_{irt}$. We suppose that ρ_{irt} is drawn for each pirate ship i in region r at date t from a uniform distribution with mean θ_{rt}. Given M_r independent draws the expected number of pirate attacks in region r at date t is given by:

$$E\left[a_{rt}\right] = \xi_{rt} M_r. \tag{1}$$

The variation in piracy attacks in equation (1) is then captured by ξ_{rt}. First, there can be factors which shape costs and benefits, including weather variation and any seasonality in shipping patterns. Second, there can be persistent changes in law and order as we saw after after the break down in law order in Puntland in 2008 which influence the likelihood of an attack being successful.

[14] To endogenize M_r, suppose that there is a fixed cost becoming an active pirate. Then we would have that a priate will enter if

$$E\left\{V_{irt} - c_{irt} : \xi_{rt}\right\} > F_{ir}$$

in which case we would also predict that M_r would be a function of ξ_{rt}, i.e.

$$M_{rt} = H\left(\xi_{rt}\right).$$

So we would have

$$E\left[a_{rt}\right] = \xi_{rt} H\left(\xi_{rt}\right)$$

and the expected number of pirate attacks will still depend on ξ_{rt} reflecting underlying law and order.

3.2 Piracy Attacks and Shipping Costs

Our core specification assumes that the dry bulk shipping market is contestable so that pricing is based on the average cost per day for each voyage.[15] We would then expect prices in that market to reflect expected piracy attacks and any other factors that influence costs.

We denote the cost per dead weight ton (DWT) per day for a ship of size s on route d in month t as:

$$C\left(s, d, t, A_{dt}\right)$$

where A_{dt} is the forecast number of attacks affecting route d at date t.[16] An effect of piracy on costs is not unrealistic as the shipping conditions at so-called "choke points" (the straits of Hormuz and Malacca, the Suez and Panama canals, the Bosporus) are known to affect freight rates. Since there are scale economies in shipping, we expect this cost function to be decreasing in s.

For simplicity, we adopt the specification:

$$\log C\left(s, d, t, A_{dt}\right) = c\left(s, d, t\right) + \gamma A_{dt} + \beta x_{dst} + \eta_{dst} \tag{2}$$

where γ is the core parameter of interest, x_{dst} are other time varying controls and η_{dst} captures other idiosyncratic factors which are uncorrelated with A_{dt}.

The cost from piracy depends on the route that the ship takes. As we have already discussed, we construct two treatment indicators for each route depending on whether it passes through the area of Somalia or Indonesia. Denote this as a dummy variable where $\delta_{dr} = 1$ if route d passes through piracy region r. Then:

$$A_{dt} = \delta_{dr} \times a_{rt}.$$

is our measure of the cost shock expected on route d where, in the core specification, a_{rt} is the recorded level of pirate attacks in month t. In the basic specification, we do not allow treatment to vary with ship size, s, or route, d.

[15] See Behar and Venables (2011) for a discussion of the extent of contestability in shipping markets. This is important for our interpretation since otherwise there would be a markup of prices over costs reflecting the extent to which ship owners have market power. In that case, part of the cost of piracy could be absorbed in lower profits.

[16] Due to the absence of good monthly data on ship traffic for our period 2002-2010 we have to use A_{dt} as a measure of piracy risk. This disregards the fact that dense traffic makes journeys less risky for each ship.

However, we will also allow for a heterogeneous effect in some specifications that we report below.

This baseline specification, in effect, supposes that the best estimate of piracy en route is the level of piracy attacks in the current month, i.e. $E[a_{rt+1}] = a_{rt}$. However, this is somewhat implausible to the extent that there are known seasonal patterns and other understandable features of the time series. Hence, below, we will consider some alternative models for the expected level of piracy attacks.

To reflect this discussion, our core empirical specification is:

$$z_{isdt} = \alpha_s + \alpha_d + \alpha_t + \gamma A_{dt} + \beta x_{dt} + \varepsilon_{isdt} \tag{3}$$

where z_{isdt} is the (log of) daily charter rate per DWT for contract i on a ship of size s, for route d in month t. The parameters $(\alpha_s, \alpha_d, \alpha_t)$ are fixed effects for ship size, route and month. The standard error ε_{isdt} is adjusted for clustering at the route level. Other controls in x_{dt} include the age of the ship and the ballast bonus per DWT (a bonus paid for empty return journeys).

The main parameter of interest is γ which we interpret as the additional shipping cost from anticipated piracy attacks. We are expecting that $\gamma > 0$. The empirical approach can be thought of as a difference-in-difference specification where ships that pass through regions where pirates are expected to attack are compared to ships using different routes over the same time period. This exploits monthly time-series variation in piracy attacks.

3.3 Core Results

Our core results are reported in Table 2 which uses the specification in (3). In column (1), the only controls are fixed effects for route, time and ship size. For the latter, the omitted ship size category is "small" Capesize ships between 80,000 and 150,000 DWTs. There is a strongly significant positive coefficient on the expected number of attacks. The point estimate says that one extra anticipated attack in a month increases the daily charter rate by a little under 0.6% in the Somalia region with no significant effect for charters that pass through the Indonesia region. While attacks in the Indonesia region continue, it is unlikely that there is much learning going on over this period and most of the effect is probably already absorbed in the route fixed effect.[17]

[17] An alternative interpretation is that increased military presence by Malaysia, Indonesia and Singapore in this period prevents an impact of piracy. See, for example,

From Table 1 we know that the mean difference in pirate attacks between the pre May 2008 and the post May 2008 period is around 14.3, this suggests that shipping costs were around 8.2% higher after the break down in law and order in Somalia which lead to increased piracy attacks.

The ship size dummy variables show evidence of significant scale economies in shipping with the smallest ships being around 62% more expensive per DWT than the excluded category. The point estimates decline across the ship size categories. This is a feature of all the estimates that we show.

In column (2), we add the additional ship controls: ballast bonus payments and the vessel's age. We find a large variation in rates paid for younger compared to older vessels with chartering rates for older vessels being significantly lower. However, the point estimates on piracy attacks do not change much after adding these controls.

In column (3), we use only data after Somali piracy increased in May 2008. The variation in piracy attacks is now identified purely from the seasonal (i.e. monthly) differences due to weather. It is encouraging to observe that the sign and significance of the piracy effect remains even though the size of the effect is much smaller. However, this is not surprising given that we are, in effect, throwing away the variation in costs due to the main breakdown in law and order in Somalia. This has an impact on the estimate as many of the costs caused by the heightened level of piracy have a fixed component due to the mean shift after May 2008. War risk insurance, for example, needs to be paid after that date regardless of the month, even though there is month or month variation with July, for example, being as risky as it was prior to the upsurge in activity (see Table 1).

Column (4) explores whether there is a heterogeneous effect across the different ship sizes travelling through the Somalia area. Due to the precision of the estimates, we cannot discern statistically distinct patterns across ship types, except for Capesize vessels which have a different coefficient compared to the other ship categories at 10%. This observation can be thought of as a robustness check on our core results since the largest Capesize vessels cannot use the Suez Canal.[18]

Overall, these results suggest that piracy in the Somalia area has a positive effect on the cost of shipping through this region. The effect is consistent

http://www.goo.gl/iy47y.

[18] We refrain from coding this category as not treated as some capesize vessels do travel through the Suez Canal (broad vessels and ships in ballast).

with around an 8% increase in shipping costs on average in the period after piracy attacks increase off the coast of Somalia. We next explore the robustness of these results.

3.4 Robustness

In this section we look at the robustness of our results to alternative ways of forecasting piracy attacks and discuss additional controls for the economic environment. We also explore alternative definitions of exposure to piracy risk.

An AR(2) Model for Piracy Attacks As an alternative to putting in the number of piracy attacks in month t, we also fitted an AR(2) process to the pattern of attacks in each region. In this case, we use

$$E\left[a_{rt+1}\right] = \hat{b}_{0r} + \hat{b}_{1r} a_{rt} + \hat{b}_{2r} a_{rt-1} \tag{4}$$

as our measure of susceptibility to piracy attacks where $\left(\hat{b}_{0r}, \hat{b}_{1r}, \hat{b}_{2r}\right)$ is the estimated parameter vector.

The results when (4) is used instead of a_{rt} to estimate (3) is in column (1) of Table 3. The coefficient on Somali piracy remains positive and significant. The change in the AR(2) prediction from the pre May 2008 period to the post May 2008 period is 9.8 which suggests an increase in shipping cost of 7.7% which is indistinguishable from our core estimate. That said, the AR2 model is unlikely to do a good job at picking up a structural break.

A Markov Chain Model for Piracy Attacks As a more structural approach, we model the level of piracy attacks using a Markov switching model based on an underlying law and order state. This will have an advantage of picking up the persistence of the shift that occurs in the piracy data and captures some of the features of the structural break analysis we perform below.

To motivate the switching model, we can return to the theoretical approach above and allow the probability of a successful pirate attack to depend on a latent state, $\ell \in \{S, W\}$ with $\xi(S) < \xi(W)$ where S stands for "strong" and W for "weak". We assume that the probability of successfully hijacking a ship and demanding a ransom is higher when law and order is weak. Using this in equation (1), the mean number of pirate attacks in state ℓ and piracy region r is

$$\mu_{r\ell} \equiv \xi(\ell) M_r, \ \ell \in \{S, W\}.$$

where $\mu_{rS} < \mu_{rW}$.

Dynamics across law and order states are modeled as a Markov chain governing the process of state transitions. This gives us a filter for emerging data on pirate attacks which can be used to construct a forecast for pirate attacks which can capture the sharp non-linear pattern in the data. We show in the appendix that this model gives the following formula corresponding to equation (1) for the expected number of attacks at $t+1$:

$$E[a_{rt+1}] = \Omega_r + (\mu_{rW} - \mu_{rS}) \lambda_r P(\ell_{rt} = W) \tag{5}$$

where Ω_r is a region-specific constant, λ_r is a measure of persistence of the process and $P(\ell_{rt} = W)$ is the probability that region r is in the weak state at time t. The latter is the only time-varying factor in equation (5) and evolves according to the history of piracy attacks. By estimating the parameters of the underlying process, we can construct an empirical counterpart to (1).[19]

This type of model, first proposed in Hamilton (1989), has been popular among time series economists modeling the non-linear properties of business cycle fluctuations. The model's core parameters are estimated using the data on attacks using the Expectation Maximization (EM) Algorithm described in Hamilton (1990) which generates an estimate of the parameters by iteration and is easy to implement.

The abrupt swings in the forecast number of attacks are driven by changes in $P(\ell_{rt} = W)$ between values that are close to zero and one while the impact of the estimated probability on expectations is driven by our estimate of $(\hat{\mu}_{rW} - \hat{\mu}_{rS}) \hat{\lambda}_r$. It is interesting to observe that the predictions made by our model are that the state shifted in April 2008 which is very much in line with the assessment of the Joint War Committee.

[19] We discuss details of the estimation in appendix B.2. Note that $P(\ell_{rt} = W)$, is a function of the particular history of attacks in region r in month t and the set of Markov chain parameters: two state-specific means, two persistence parameters which together determine λ_r and two state-specific variances. To forecast piracy attacks, we use the observed number of attacks in month t to calculate the probability $P(\ell_{rt} = W)$ that a region is in a weak state given a set of known parameters. Equation (5) shows that if $P(\ell_{rt} = W)$ increases then the expected value of attacks next month increases by $(\hat{\mu}_{rW} - \hat{\mu}_{rS}) \hat{\lambda}_r$. The estimate for $(\hat{\mu}_{rW} - \hat{\mu}_{rS}) \hat{\lambda}_r$ for Somalia is 11.45 attacks.

The results when (5) is used instead of a_{rt} to estimate (3) is in column (2) of Table 3. The coefficient on Somali piracy remains. Moreover, this model which allows for the persistence in piracy attacks (an important feature of the data), predicts an estimate of 11.8% which is somewhat higher than the estimate from column (1) of Table 2.

Omitted GDP Trends It is important to observe that, by including time dummy variables (for each month), we are controlling for general trends in the global shipping market. These are important over this period given that the economic crisis erupts around 2008 while the capacity of bulk shipping grows considerably. For this to create a problem for us, it would have to be the case that the routes that we have classified as being treated are differentially affected by changes in market conditions in a way that increases shipping costs of bulk shipping. The main trend in this period is, however, a switch of bulk trade in Asia away from Europe and towards other Asian countries, Australia and the Americas.[20] This would work against us as it would put a downward pressure on prices for bulk charter agreements between Europe and Asia. In any case we attempt to control for changes in the economic fundamentals in two ways.

Column (3) of Table 3 adds GDP growth controls for the origin and destination of each route. Due to the coarseness of (especially) the destination data, discussed further in Appendix A, we were forced to aggregate to regional GDP for this exercise. Controlling for either annual regional GDP levels (regressions not shown), interpolated monthly regional GDP levels (regressions not show) or regional GDP growth, as shown in column (3) does not change the pattern of coefficients.

In column (4), we further address this concern by incorporating separate time trends for each region. The core finding linking piracy attacks is robust although is somewhat smaller in size compared to column (1) or Table 1.

Alternative Treatment Definitions In order to match the piracy data with the shipping data, it was necessary to impose some structure by defining regions that are susceptible to piracy. We assigned routes to the treatment group if the computed shortest path of the route crossed one of our piracy regions. But evidently, there is some leeway in how this could be done and, in the following specifications, we show that our results are robust to various

[20] See the detailed discussion in UNCTAD 2011 and UNCTAD 2010.

ways of assigning the treatment and definitions of areas that are subject to piracy threats. The results are shown in columns (5) to (7) of Table 3.

In column (5) we use more narrowly defined piracy regions focusing on two key choke points: the Gulf of Aden and the Strait of Malacca.[21] The results show that piracy in the Gulf of Aden still has a significantly positive impact on shipping prices through that area. The point estimate is somewhat larger. However, note that we used only a smaller set of attacks so that the difference between pre May 2008 and post May 2008 now only is 7.4 attacks. The overall magnitude of the effect of piracy is very similar to that reported in the core specification.

Column (6) shows the results when we attempt to disentangle the effect of Somali (Indonesian) piracy on trade through the Gulf of Aden (Strait of Malacca) from the effect on trade in the broader regions. We now use the number of attacks from our main specification and apply it to two subgroups of maritime routes: a) ships that travel through the Gulf of Aden (Strait of Malacca) and b) ships that travel through Somalia (Indonesia), but not through the Gulf of Aden (Strait of Malacca). The key insight from the specification reported on column (6) of Table 3 is that we also find a cost of piracy for routes that do not travel through the Gulf of Aden but through the broader Somalia area. This is important because it suggests that trade between the Middle East and Asia and Africa is affected by Somali piracy as well. Our welfare estimates will take this into account.

Columns (7) and (8) in Table 3 look at robustness regarding the treatment. We need to be wary that ships could be travelling alternative routes in order to avoid the canal fees or the piracy regions. We would expect such re-routing to be more of an issue for maritime routes for which there is a feasible alternative route which does not use the Suez Canal and which is not significantly longer than passing through the piracy region. To examine this, we used our algorithm to compute alternative routes while adding the constraint that vessels cannot travel through the Suez Canal. We then assign treatment based on these alternative routes if they are at most 10% (column (7)) or 20% (column (8)) longer than the Suez Canal route. The point estimate for the Somalia area becomes slightly higher but is indistinguishable from our main result in Table 2 column (1).

[21] For the Malacca strait we use the maritime area bounded by latitude $\in [1, 7.4]$ and longitude $\in [95.8, 104.7]$. For the Gulf of Aden, the bounding box is given by latitude $\in [10.5, 17]$ and longitude $\in [40, 52.2]$.

3.5 Extended Results

We now extend the results in two ways. First, we explore the possibility that, as well as affecting costs, piracy attacks also changed the desirability of shipping on routes affected by piracy. Second, we use data on piracy risk and wind speed to analyze the "reduced form" impact these variables have on shipping costs.

Effects on Shipping Piracy attacks could be a deterrent to shipping goods through areas that are susceptible to piracy attacks. Here we look at two possible dimensions of this. First, piracy could affect the amount of traffic on piracy routes. Second, piracy could affect the composition of ships going through the piracy areas.

The Suez canal offers a way to analyze the impact of piracy on trade volumes. We obtain monthly data on the quantities of cargo in deadweight tons through the Suez canal for each month of our sample period. The task of identifying a piracy effect in this time series is complicated by the fact that the failure of Lehman Brothers, an event which signalled the onset of the most serious phase of the global financial crisis, occurs in September 2008 - only shortly after the upsurge in piracy. As is well known, this led to a significant reduction in world trade.

To disentangle the effect of the economic crisis from the effect of piracy we look for breaks in the time-series of cargo traffic and try to identify in which month, if any, a break took place. Specifically, we use the method described in Bai (1997) to determine the break points in the series for cargo volumes and for piracy attacks in the Somalia region. For the trade volume exercise, we search for the optimal location and number of break-points according to a BIC criterion using the following model:

$$Cargo_t = \beta_0 + \beta_1 t + \epsilon_t$$

for all possible dates t. We find exactly one break-point for the period following November 2008, roughly two months after Lehman Brothers failed. Bai and Perron (2003) propose a method for obtaining a confidence band around an estimated break-point. Applying their approach, we find that with 99% confidence the break occurs in the period following October- to December 2008. This makes sense given that goods already in transit and on which shipping contracts had been agreed would not have been affected by the Lehman crash. Applying the same approach to piracy attacks, we find that the break in the series is in July 2008. This is different from the break point in the cargo series. That said, the 99% confidence band for the break in the mean level of piracy is a lot wider and ranges between August 2007 and August 2008, the latter still being before the Lehman's failure.

This motivates running regressions in which we include a dummy variable for November 2008 onwards to pick up the effect of Lehman Brother's failure when looking for an effect of piracy attacks on the quantity of cargo being shipped through the Suez canal. Thus we run

$$Cargo_t = \lambda_0 + \lambda_1 a_t + \lambda_2 Lehman_t + \lambda_3 t + \eta_t. \tag{6}$$

where $Lehman_t$ is a dummy variable that switches from zero to one in November 2008.

The results from running (6) are in columns (1) and (2) of Table 3. Column (1) shows that if we only include the level of piracy attacks, then we get a large and significant effect of piracy attacks on cargo; the effect amounts to a 30% reduction at the mean level of monthly piracy attacks after May 2008. Once we include the structural break identified by the method outlined above, this becomes much smaller in size and insignificant as column (2) shows.

These results do not suggest that piracy had an effect on the amount of cargo shipped through the Suez canal. That said, the 95% interval of the estimate in column (2) is consistent with an negative effect on trade of up to 3.5% which is in line with the Feyrer (2009) estimates of the effect of distance cost on trade.[22] Using his estimates an increase of trade costs by 8% would yield a decrease in trade between 1.6% and 4%.

Effects on Average Ship-Size One possible reaction to piracy would be to use ships that are less susceptible to piracy attack. We look for evidence of a shift in composition by looking at the average DWT of ships in our data over the period and see if this varies in response to the threat of piracy. Thus, we use our data at the route level to calculate the average weight of a ship on route d at t and run the regression:

$$DWT_{dt} = \alpha_d + \alpha_t + \gamma A_{dt} + \psi_{sdt}$$

[22] The average traffic pre May 2008 was 43,000 metric tons. This implies a point estimate for the decrease in traffic of $\frac{32.89*14.33}{43000} = 1.1\%$. The upper bound is calculated from the 95% interval $1.1 + \frac{1.96*36.9*14.33}{43000} = 3.5\%$.

where (α_d, α_t) are route and month dummies. The effect of piracy is now identified from variation within a route over time using the same treatment assignment as in our core results above.

The results is reported in column (3) of Table 4. While there is a negative coefficient on Somali piracy attacks and a positive coefficient on Indonesian piracy attacks, these coefficients are not significant at conventional levels. Thus, there does not seem to be any substitution in ship size in response to piracy.

War Risk Declaration and the Impact of Wind Speed Declaring an area as a special war risk area is a significant event in the insurance industry and is bound to affect insurance costs as well as being likely to trigger a raft of defensive measures. So instead of using the level of piracy attacks, we can simply use these dates. The representative of the marine hull war insurance business in the London market, the Joint War Committee, took the Strait of Malacca off its list of areas under special war risk in August 2006 and added the Gulf of Aden in May 2008. We now use dummy variables to represent these events in equation (3) instead of the level of piracy attacks.[23]

The result is in column (4) of Table 4. The coefficient on the war risk dummy suggests around a 13% increase in shipping costs (a larger effect than was found in the baseline estimate of Table 1). There is a weak effect on Indonesian piracy now which could highlight the importance of the insurance status as opposed to the actual level of attacks. In any case the effect is not very robust and we therefore ignore it.

Given the discussion in section 2 one interesting issue is how far during the "treatment period" identified by the Joint War Committee, wind speed variation affected shipping costs. Given that supplementary insurance to pass through high risk areas is priced based on specific weeks in high risk zones, we might expect that it would be. We look at this, by allowing the lagged wind speed to be interacted with the treatment dummy since, as we have already shown, piracy attacks are extremely seasonal. The results are reported in column (5) of Table 2. Here we find a negative coefficient on wind speed, i.e. there is a smaller effect on costs with high wind conditions which are likely to reduce the incidence of piracy.

[23] May 2008 was in our confidence interval based on our structural break analysis above but does not coincide with the date that was identified there which was July 2008. The results are fairly similar if we use a dummy that is equal to one at this slightly later date.

Figure 4 illustrates the fitted values from column (5) Table 4. It shows the shipping cost increase on Somalia routes predicted by the Somalia war risk, wind speed and their interaction. The graph clearly shows the jump due to pirate activity in May 2008. However, it also illustrates the strong seasonality induced by the seasonality in piracy. After May 2008 shipping costs are roughly twice as high when wind conditions favor piracy attacks.

These additional results increase our confidence in the results and the proposition that shipping costs increase due to the risk of maritime piracy attacks.

4 The Welfare Cost of Piracy

We now discuss what our results imply for the welfare cost of piracy. Our welfare criterion takes the transfer from consumers of traded goods (who ultimately bear the cost) to pirates as given. We ask what an efficient transfer, i.e. via a tax, of the same magnitude would cost the consumers and compare this to the cost that piracy imposes.

4.1 Framework

Piracy leads to a transfer of resources to pirates via ransoms. Resources are used by pirates in securing these ransoms and by ship owners and governments in resisting them. The costs of the ransoms and damage to ships are also borne directly by those who pay them. These costs are pooled across the industry through insurance. Resources are also used in writing insurance costs and in the lengthy process of negotiations with pirates. As with any transfer program, there is a question of who pays in the end. If the market for shipping is competitive then any increased cost will be passed on to consumers of the final goods in the form of higher prices. And full forward shifting is the benchmark that we consider.

Suppose that there is a composite traded good, X, for trade between locations which is susceptible to piracy attacks. Suppose that shipping demand has a fixed coefficient technology so that demand for shipping is νX. The number νX is best thought of as ton days, i.e. as the number of shipped tons multiplied by the average maritime journey time.[24] We assume that the

[24]This view is very much in line with the usual measure of mile tons. For an interesting discussion regarding this see Stopford (2009). We disregard variable shipping speeds which

good X is sold in a competitive market and that the marginal cost per unit is denoted as $\psi + \phi$ where ψ is the production cost and ϕ is the shipping cost per unit. Suppose that there is a representative consumer with utility $U(X)$ and additive quasi-linear utility. This allows us to ignore general equilibrium effects. The representative consumer's optimal consumption is given by:

$$U'\left(\hat{X}(\psi + \phi)\right) = \psi + \phi$$

and the indirect utility from consuming tradeable goods of the relevant kind is

$$V(\psi + \phi) = U\left(\hat{X}(\psi + \phi)\right) - \hat{X}(\psi + \phi)[\psi + \phi].$$

As we have already seen, piracy increases shipping costs, ϕ. Suppose that part of that cost increase leads to a transfer to pirates denoted by T and that that we attach a "welfare" weight of μ to these transfers, i.e. to pirate welfare. It is somewhat debatable what this weight should be. Ransoms transfer income to a poor country (Somalia) but they go directly to a particular group, i.e. organized criminals. It is far from clear how these benefits may trickle down to the wider population.[25] We feel that it is best to be agnostic about this and base our welfare approach on Coate (2000). Using his reasoning, we should care principally that any transfer made to pirates is accomplished in the most efficient way and hence the welfare loss are the resources spent in the process of delivering the transfer.

For fixed μ, welfare is

$$W(\phi) = V(\psi + \phi) + \mu T.$$

Now suppose that, as above, the cost of shipping final goods is

$$\phi(\Delta) = \nu[c + \Delta]$$

where c is the base transport cost per unit of shipping expressed in USD and Δ is the increase in transport costs due to piracy.

The part of the cost (again in USD) that is a transfer to pirates is denoted by $\tau(\Delta)$. And the total transfer received by pirates is

$$T(\Delta) = \tau(\Delta)\nu\hat{X}(\psi + \nu[c + \Delta]).$$

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makes the two measures equivalent.

[25] Shortland (2011) provides some evidence that piracy revenue trickles into Somali society and has a positive developmental effect.

In order to be agnostic about μ, suppose we consider a thought experiment where we replace piracy with a tax on shipping, the proceeds of which are transferred to the pirates, yielding the exact level of net revenues as they now receive from engaging in piracy. Proposing a tax on shipping seems more reasonable than considering lump-sum taxation in this instance and it would clearly fall on the same group as those who currently bear the cost of piracy.

The amount of the required unit tax, t, is defined by

$$t\nu\hat{X}\left(\psi+\nu\left[c+t\right]\right)=\tau\left(\Delta\right)\nu\hat{X}\left(\psi+\nu\left[c+\Delta\right]\right). \tag{7}$$

This equation illustrates the source of the inefficiency of piracy attacks. The increase in charter rates Δ due to piracy is not fully captured by the pirates so that $t\leq\tau\left(\Delta\right)<\Delta$. Were the transfer efficient then $t=\tau\left(\Delta\right)=\Delta$.[26] In other words, a tax has only the usual excess burden familiar to public finance economists while piracy leads to additional costs such as the costs from the guard labor associated with combatting piracy, damage to ships, negotiation costs to release hijacked ships and costs of additional insurance.

Since the tax keeps the transfer to pirates constant, the welfare cost of piracy is measured by:

$$L\left(\Delta\right)=V\left(\psi+\nu\left[c+t\right]\right)-V\left(\psi+\nu\left[c+\Delta\right]\right) \tag{8}$$

which, by construction, does not depend on the welfare weight μ.

4.2 Benchmark Estimate

A benchmark (first-order) estimate of (8) can be found by ignoring any trade response (i.e. demand response by consumers). Thus $\hat{X}\left(\psi+\nu\left[c+\Delta\right]\right)$ is completely inelastic and $t=\tau\left(\Delta\right)$. In this case (8) becomes:

$$L^{1}\left(\Delta\right)=\left[\Delta-\tau\left(\Delta\right)\right]\times\nu\hat{X}. \tag{9}$$

Estimates of (9) for the year 2010 are in column (1) of Table 5. Details of all calculations are in Appendix D. In Panel A we use the detailed data available from the Suez Canal authority on the total amount of tons shipped through the Gulf of Aden. We translate this number into an amount of DWT×days

[26] Of course, a tax would be costly to administer and we are not including this in our thought experiment. But evidently that could be part of the calculation too.

by using the mean bulk ship speed (from Stopford, 2009) and the average length of the trip in the respective sample.[27] Panel B adds an estimate of the DWT×days that do not travel through the Gulf of Aden but through the broader Somalia area.

To get a feel for the plausible range, we present a low and a high estimate. Our low estimate uses the coefficient from column (1) in Table 2 for the Gulf of Aden and estimates in column (6) Table 3 for the broader Somalia area. Our high estimate uses column (4) of Table 4 for the Gulf of Aden and the respective specification reported in the Appendix D for Somalia.

We illustrate our calculations of $L^1(\Delta)$ with the low estimate in panel A of Table 5. We use the increase in expected attacks in Table 1 and apply it along with column (1) of Table 2 to the average rate charter rate of 0.4726. This yields the following estimate of total piracy costs:

$$\begin{aligned} \Delta \times \nu\hat{X} &= 0.00572 * 14.33 * 0.4726 \times 30.3 * 646,064,000 \\ &= 758 \text{ million USD} \end{aligned}$$

for 2010.[28] This is around 94,000 USD for a Panamax ship.

Our estimate of $\tau(\Delta) \times \nu\hat{X}$ is the gross ransoms paid less the costs incurred by pirates in generating this. A reasonable figure for the gross ransoms is 200 million USD. And netting out the costs of generating these, suggest profits from piracy in the region of 120 million USD.[29] Together with our estimate of $\Delta \times \nu\hat{X}$ this sums to the number

$$L^1(\Delta) = [758 - 120] \text{ million USD} = 638 \text{ million USD}.$$

Even from this lower-bound estimate it should become clear that the additional costs incurred due to the threat of piracy vastly exceeds what it would cost to offer pirates a tax-financed transfer of comparable magnitude to the revenues that they earn.

[27] We make the assumption all of this cargo is comparable to ours in terms of its exposure to higher shipping costs, journey length and travels though the Gulf of Aden.

[28] Obviously this number is subject to a large margin of error. For example, container traffic is likely to be less affected. Were we to suppose that there was no effect on container ships then the size of the affected deadweight tonnage would be only 279,063,000 and the cost would be considerably lower. We abstract from this as the value of container goods is likely to be much larger which would incease the cost.

[29] For a careful and transparent calculation see `http://www.goo.gl/5T9nW`. This is in line with estimates in Geopolicity (2011).

Panel B shows, not surprisingly, that the estimated cost is much higher when we calculate the value of shipping for the wider region including trade routes that do not cross the Gulf of Aden. Our estimates of the welfare cost increase by around 40%.

4.3 Extended Estimates

There are further reasons to believe that our estimates in column (1) of Table 5 are a lower bound. We now consider two of these: (i) the possibility of a demand response which reduces trade and (ii) the possibility that only some of the cost of piracy is paid by the charterer.[30]

Allowing for the possibility of a demand response, we show in the appendix D.2 that the welfare loss caused by a decrease in trade can be approximated by a simple scaling factor on our estimate above, which depends on the elasticity of trade with respect to transport costs, $\hat{\eta}$, and is given by

$$L^2(\Delta) = L^1(\Delta)\left[1 + \frac{1}{2}\frac{\Delta - \tau(\Delta)}{c + \Delta}\hat{\eta}\right]. \tag{10}$$

In other words, the loss due to trade reduction can be approximated by the trade elasticity with respect to transport costs times the share of piracy costs in total transport costs.[31] Obviously, $L^2(\Delta) > L^1(\Delta)$ as long as $\hat{\eta} > 0$.

There are several possible numbers we could use for $\hat{\eta}$. Recent estimates from Feyrer (2009), who uses the Suez Canal closure from 1967 to 1975 as a shock to distance that a value of $\hat{\eta}$ between 0.2 and 0.5 is reasonable. This a little lower than the estimate found in a meta study in Disdier and Head (2008) which is 0.9. However, given the context of the Feyrer (2009) study, we use an estimate of 0.5 in column (2) of Table 5. This suggests that $L^2(\Delta)$ is larger than $L^1(\Delta)$ by a factor of between 1.017 and 1.03. This suggests that the additional welfare loss due to changes in quantity are relatively marginal (consistent with this being a second-order effect in our context). This is confirmed when comparing the new estimates in column (2) of Table 5 with column (1).

[30] Similarly, if we believe that the market for ship capacity is not competitive, we could see that piracy related expenses may be forwarded with a markup. This is a possibility we do not explicitly consider further.

[31] Note that we calculate an upper bound this way as charter costs are just a part of total (maritime) transport costs.

Column (3) of Table 5 allows for the possibility that the increase in chartering rates fails to capture *all* of the additional costs imposed by piracy. In particular, we check what would happen if costs were split between ship owner and charterer according to the "general average rule" as it is known in the shipping industry. This rule shares the costs of protecting the ship in proportion to the value of the vessel and the cargo. Assume then that a share ζ of the piracy costs are borne by the ship-owner. The charter rate increase Δ is the transfer that compensates the owner for piracy costs over and above what the charterer bears. Then if charter rates increase by Δ due to shipping costs the overall cost to the industry is now given by $\frac{\Delta}{2\zeta-1}$.[32] This yields our third measure of welfare cost of:

$$L^3(\Delta) = \left[\frac{\Delta}{2\zeta - 1} - \tau(\Delta)\right] \times \nu\hat{X} \tag{11}$$

which is reported in column (3) of Table 5. This leads to estimates that are somewhat larger than in column (1) of Table 5. For example, the low estimate allowing for general averaging is 130% higher. The details on the calibration of ζ can be found in Appendix D.3.

Adding all this together, our Somalia estimates are between 0.9 billion USD and 3.6 billion USD. While the range of estimates is quite large, the comparison between these numbers of the transfer received by pirates of only 120 million USD is telling. The welfare costs suggested are indeed substantial.

4.4 Predation versus Taxation

We can use equation (7) in the previous section to calculate t - the tax rate on shipping through Aden that would yield the same revenue now going to pirates. Of course there is no reason to expect that such a tax and transfer system provides a realistic solution to the piracy problem. Identifying those

[32] To get an intuition for the formula assume that the shipping cost is 100. The owner has additional costs due to piracy of 20 and the charterer pays 10. The charter rate will go up by 10 due to piracy but overall costs due to piracy is 30. And, indeed, $\frac{1}{2\zeta-1} = \frac{1}{2\frac{2}{3}-1} = 3$ in this case.

who should receive the transfer would be impossible to identify. However, it does provide another way of thinking about the costs involved.

Disregarding the effect on trade we get this tax rate from the following calculation:

$$\begin{aligned} t &= \frac{\tau(\Delta)\,\nu\hat{X}\,(\psi+\nu\,[c+\Delta])}{\nu\hat{X}\,(\psi+\nu\,[c+\Delta])} \\ &= \frac{120 \text{ million USD}}{0.4726 * 30.3 * 646,064,000 + 0.4648 * 20.67 * 578,000,000} \\ &= 0.008. \end{aligned}$$

This implies that a tax rate of just 0.8% on chartering would be needed to generate a transfer of comparable magnitude to that generated by piracy. This contrasts with our estimates of the increase in shipping costs of between 8% and 13%. This calculation suggests that predatory activity of the kind undertaken by pirates is between 10 and 16 times more costly as a means of giving a similar level of resources to pirates than taxation would be.[33]

It is worth dwelling on the reason why these costs are so high and how far they provide insight into debates about the costs of failure to establish law and order. There are two key factors: (i) the fact that piracy causes direct damage and loss (ii) the fact that efforts to establish law and order are fragmented.

Direct damage comes partly from the damage to property. However, it also comes in part from the fact that pirates have to hold ships for long enough to establish their credibility. This is like an inefficient war of attrition which increases the cost of doing business and creates delay over and above the cost of the ransom.[34]

Somalia is now the focus of international attention although with limited progress. In the context of potential donor interest, it is instructive to consider how many Somali's could be hired for one year using the additional resources that we estimate are expended by the shipping industry in response to the threat of piracy. Using the numbers in panel B of Table 5, a conservative estimate of the costs of piracy to the shipping industry is about 1.05

[33] Of course, this thought experiment assumes naively that the pirates could be identified and that they could be transfers similar to what they currently earn from piracy.

[34] For an analysis of a strikingly related ransom bargaining process see Ambrus et al. (2011) who analyze ransom negotiations during a period of piracy in the Meditteranean sea from 1575-1739.

billion USD. We use wage data from the Somali Food Security and Nutrition Analysis Unit (FSNAU) presented in Shortland (2011) to calculate a yearly wage of about 870 USD.[35] This means that the extra spending due to piracy could finance one year of employment for more than 1.2 million laborers at the going market rate in 2010. This does not mean that such a transfer scheme would be realistic or that it would prevent piracy. But it illustrates the scale of losses to the industry relative to the reality of the Somali economy.

4.5 Investing in Security

The insurance industry appears to be offering some discounts if a vessel is carrying armed guards through the high risk areas. However, our discussions with industry participants suggest that these discounts tend to be small. With this caveat in mind, we can explore an alternative way to understand the inefficiency by calculating the costs of putting private security crews on every ship.[36]

From conversations with security firms, we know that they charge about 3000 USD for a security crew of four per day.[37] The guards typically board the vessel on key points before entering the Indian Ocean. The boarding points are Sri Lanka, the Strait of Hormuz, Madagascar and an anchored vessel in the Red Sea off Djibouti. We compute the average time it takes for a vessel to travel between the boarding points in Sri Lanka, the Strait of Hormuz, Madagascar and the Red Sea. Based on this we compute the total cost of hiring security crews for traffic going through the Suez Canal. We arrive at an estimate of 302 million USD and 486 million USD for 2010. Given that no ship with security teams onboard has been hijacked up to now this provides an interesting benchmark for the costs in this area from Table 5 which suggests a cost which lies between 640 million USD and 2.4 billion USD

[35] In 2010 the highest daily wage paid in Somalia was about 100,000 Somali Shillings (SSh). Assuming 261 work days and an exchange rate of about 30,000 SSh/USD this implies a yearly wage of about 870 USD.

[36] We thank Daron Acemoglu for suggesting that we look at this and Marit Rehavi for suggestions on data.

[37] This cost is well in the interval of cost estimates for US security contracts in Iraq. The 2010 United States Government Accountability Office report "Warfighter Support: A Cost Comparison of Using State Department Employees versus Contractors for Security Services in Iraq", for example, gives a range of these costs between 430 USD and 7600 USD for four persons per day.

for this area. Taken at face value, it suggests that there is underinvestment in security guards.

When it comes to fragmented law and order, combatting piracy currently has an array of actors all investing in the hope of dealing with the problem. This includes the somewhat uncoordinated efforts of governments. The most efficient outcome would be to establish a monopoly of violence over the seas as we see in established states.[38] Otherwise, each actor will invest until the marginal benefit equals the marginal cost.[39] By protecting particular groups this will tend to shift piracy to other vessels rather than reducing attacks. Thus a pirate repelled by one ship is free to go and attack another ship. Thus it is inefficient to leave piracy protection in private hands.

But international cooperation suffers from free-rider problems as well. While the international community has now attempted to introduce naval patrols to combat Somali piracy, this is extremely expensive and requires international diplomacy between a range of states. Currently member countries of the EU and Nato, the US, China, Russia, India, Saudia Arabia, Iran and Japan deploy maritime forces in the area. They patrol an area of sea approximately equal to the size of western Europe.

But difficulties of coordination is not new as revealed, for example, in the correspondent report on Chinese piracy in *The London and China Telegraph* from 4th February 1867 noted that

> "Besides we are not the only Power with large interests at stake. French, Americans, and Germans carry on an extensive trade [...] Why should we then incur singly the expense of suppressing piracy if each provided a couple of gunboats the force would suffice for the safety foreign shipping which is all that devolves upon [..] why should the English tax payer alone bear the expense?"

It seems striking how little progress on these issues has been made more than 100 years later.

While somewhat sketchy, our estimates in Table 5 can be augmented to include the costs of naval operations which try to limit pirate activities. The

[38] See Besley and Ghatak (2010) for development of this argument in relation to property rights enforcement.

[39] In addition, there is anecdotal evidence of an arms race in which pirates are better and better equipped and ship owners move from minor ship modifications to hiring security crews. For a general discussion of these issues see de Meza and Gould (1992).

costs of Atalanta for the European Union in 2009 was 11 million USD.[40] To this we need to add the costs of the EU member countries. The only available estimates indicate that additional operational costs for the German military involvement (1 vessel, 300 personal) in 2010 was around 60 million USD.[41] Since the overall size of the Atalanta mission is between 4 and 7 vessels this indicates total costs of about 340 million USD for the Atalanta mission. In addition to Atalanta there are two more operations which are, at least partially, occupied with preventing piracy attacks: NATO's Ocean Shield and the Combined Force 151. Causality from piracy to the presence of some of the military forces in the Arabian sea is harder to establish. For example, the Combined Force 151 includes two US aircraft carriers stationed there.

The current reliance of the international community on Naval patrols to combat piracy could succeed in reducing pirate activity further. In the end, the most promising long-term solution would seem to be to restore a functional Somali state which can deny pirates safe haven, thereby dealing with the problem at source.

5 Concluding Comments

Piracy is an important source of predation which creates economic disruption. In this paper, we have used estimates of its effect on shipping prices to estimate the welfare cost of Somali piracy.

While what we have studied here is only one specific kind of lawlessness, estimates of the costs of predatory activity in any specific context are rare. We have shown that the cost of piracy is large relative to the size of the transfer to pirates. This is particularly true compared to a tax levied on shipping to pay a transfer to pirates.

The analysis further underlines the difference between organized extraction by the state in the form of taxation and disorganized predation. We estimate that the latter is at least ten times more costly. In the language of Olson (2000), pirates are roving bandits while the state is a stationary bandit and hence is in a better place to organize extraction at lower costs.

[40] See `http://www.goo.gl/hrqPA`, accessed on 10.04.2012.

[41] Deutscher Bundestag Drucksache 17/179. *Fortsetzung der Beteiligung bewaffneter deutscher Streitkräfte an der EU-geführten Operation Atalanta zur Bekämpfung der Piraterie vor der Küste Somalias.*

Without a return to strong law and order in Somalia, it seems unlikely that these welfare costs will disappear any time soon.

References

[1] Acemoglu, Daron, Simon Johnson and James A. Robinson, (2001). The Colonial Origins of Comparative Development: An Empirical Investigation. *American Economic Review*, 91, 1369-1401.

[2] Ambrus, Attila, Eric Chaney and Igor Salitskiy, (2011). Pirates of the Mediterranean: An Empirical Investigation of Bargaining with Transaction Costs. *mimeo*.

[3] Bai Jushan, (1997). Estimation of a Change Point in Multiple Regression Models, *Review of Economics and Statistics*, 79, 551-563.

[4] Bai Jushan, and Pierre Perron, (1998). Estimating and Testing Linear Models With Multiple Structural Changes, *Econometrica*, 66, 47-78.

[5] Bai Jushan and Pierre Perron, (2003). Computation and Analysis of Multiple Structural Change Models, *Journal of Applied Econometrics*, 18, 1-22

[6] Bandiera, Oriana, (2003). Private States and the Enforcement of Property Rights: Theory and Evidence on the Origins of the Sicilian Mafia. *Journal of Law, Economics and Organization*, 19(1): 218-244.

[7] Behar, Alberto and Anthony J. Venables, (2011). Transport Costs and International Trade. in *Handbook of Transport Economics*, edited by André de Palma, Robin Lindsey, Emile Quinet and Roger Vickerman, Edward Elgar.

[8] Bendall, Helen B., (2011). Cost of piracy: A Comparative Voyage Approach. *Maritime Economics & Logistics*, 2(12):178–195.

[9] Bensassi, Sami and Inmaculada Martínez-Zarzoso, (2011). The Price of Modern Maritime Piracy. Ibero America Institute for Econ. Research (IAI) Discussion Papers 213.

[10] Besley, Timothy and Maitreesh Ghatak, (2010). Property Rights and Economic Development. In Rodrik, D. and Rosenzweig, M., editors, *Handbook of Development Economics*, volume V, chapter 68.

[11] BMP4, (2011). *Best Management Practices for Protection against Somalia Based Piracy, Version 4*. Witherby Publishing Group Ltd, Edinburgh.

[12] Coate, Stephen, (2000). An Efficiency Approach to the Evaluation of Policy Changes. *Economic Journal*, 110:437–455.

[13] de Meza, David and J. Robert Gould, (1992). The Social Efficiency of Private Decisions to Enforce Property Rights. *Journal of Political Economy*, 100(3): 561-580.

[14] Donaldson, David, (2010). Railroads of the Raj: Estimating the Impact of Transportation Infrastructure. *NBER Working Paper*, 16487.

[15] Disdier, Anne-Célia and Keith Head, (2008). The Puzzling Persistence of the Distance Effect on Bilateral Trade. *Review of Economics and Statistics*, 90(1):37–48.

[16] Dixit, Avinash, (2004). *Lawlessness and Economics: Alternative Modes of Governance*. Princeton University Press, New Jersey.

[17] Feyrer, James, (2009). Distance, Trade, and Income: The 1967 to 1975 Closing of the Suez Canal as a Natural Experiment. *NBER Working Paper*, 15557.

[18] Geopolicity, (2011). The Economics of Piracy: Pirate Ransoms and Livelihoods off the Coast of Somalia.

[19] Hansen, Stig J., (2009). Piracy in the greater Gulf of Aden: Myths, Misconception and Remedies. Norwegian Institute for Urban and Regional Research (NIBR) Report 2009:29.

[20] Hamilton, James, (1989). A New Approach to the Economic Analysis of Nonstationary Time Series and the Business Cycle. *Econometrica*, 57(2):357–384.

[21] Hamilton, James, (1990). Analysis of Time Series Subject to Changes in Regime. *Journal of Econometrics*, 45:39–70.

[22] Hastings, Justin V., (2009). Geographies of State Failure and Sophistication in Maritime Piracy Hijackings. *Political Geography*, pages 1–11.

[23] Leeson, Peter, (2007). An-arrgh-chy: The Law and Economics of Pirate Organization. *Journal of Political Economy*, 115(6):1049–1094.

[24] MARSH, (2011). Piracy - The Insurance Implications.

[25] North, Douglas C., (1968). Sources of Productivity Change in Ocean Shipping. *Journal of Political Economy*, 76(5):953–970.

[26] Olken, Benjamin and Patrick Barron, (2009). The Simple Economics of Extortion: Evidence from Trucking in Aceh. *Journal of Political Economy*, 117(3):417–452.

[27] Olken, Benjamin and Rohini Pande, (2011). Corruption in Developing Countries. NBER Working Paper No. w17398.

[28] Olson, Mancur, (2000). Power and Prosperity: Outgrowing Communist and Capitalist Dictatorships. Oxford University Press, Oxford.

[29] One Earth Future Foundation, (2010). The Economic Costs of Maritime Piracy. *Working paper.*

[30] One Earth Future Foundation, (2011). The Economic Cost of Somali Piracy 2011. *Working Paper.*

[31] Rose-Ackerman, Susan, (2010). The Law and Economics of Bribery and Extortion. *Annual Review of Law and Social Science*, 6: 217-238.

[32] Shortland, Anja, (2011). "Robin Hook": The Developmental Effects of Somali Piracy. *DIW Discussion Papers*, 1155.

[33] Stopford, Martin, (2009). *Maritime Economics.* Routledge, New York, 3rd edition.

[34] UNCTAD (2009). Review of Maritime Transport. *Report by the UNCTAD secretariat.*

[35] UNCTAD (2010). Review of Maritime Transport. *Report by the UNCTAD secretariat.*

[36] UNOSAT (2010). Spatial Analysis of Somali Pirate Attacks in 2009.

A Data

This appendix discusses the data sources and generation of variables. Table A1 provides summary statistics for our data.

A.1 Chartering Contracts

The data on shipping prices comes from the web-site of N. Cotzias Shipping Consultants which provides monthly reports of the time charter market for the period November 2002 until December 2010.[42] The data is comprised of 33,529 individual fixtures in the dry bulk cargo segment of the market.

It contains details on the vessel that was chartered, the chartering company, the month in which the charter was fixed and the approximate date (day-range / months), when the charter would commence. The details on the vessel give us the current ship name, the year it was built and its deadweight tonnage. The pricing information contains the daily rate in USD, along with a ballast bonus. From these we construct the daily rate per deadweight ton and the ballast bonus per deadweight ton. On average, about 9% of the charters in our sample include a ballast bonus.

The chartering information provides details about the location of the vessel origin and the vessel destination, i.e. where it will be handed back to the ship owner. Due to the nature of the chartering market, market participants have an active interest in reporting the vessels delivery- and redelivery locations. However, this information comes with varying levels of detail. In particular the redelivery location may either be a port, a country, a maritime region or it may be missing. Further challenges include that sometimes, the port name is spelled wrongly or abbreviations were used. We harmonize the data to country-level pairs. The raw data contains 2,430 distinct delivery- or redelivery locations. We proceeded in two steps:

1. Try an exact match based on a database of port names.[43]. This will give us, in case of an exact match, a port and the country in which this port is located. In case no exact match was found, we used the Google Search

[42] In early 2011, Cotzias merged with Intermodial (www.intermodal.gr). As of 25th January 2012, the Cotzias data was available on `http://www.goo.gl/g5d0c`.

[43] This database contains the details and locations of 27,625 ports all over the world. They include all major ports, but also smaller ports and docks. It can be accessed on `http://www.goo.gl/s59UE`

Engine to get a spelling suggestion (in case there was a misspelling in the raw data) and try it again with the corrected spelling. Through this, we are able to filter 570 locations, which account for roughly 2/3 of the observations.

2. For the remainder of the delivery- and redelivery locations, we proceed by performing Google searches in a semi-automated way, double checking and validating the results manually.

A.2 IMB Piracy Data

The IMB runs the piracy reporting centre which can be contacted 24 hours by vessels under attack. The information received from the ship Masters is immediately relayed to the local law enforcement agencies requesting assistance. In addition, the information received from the ship Masters is broadcast to all vessels in the Ocean region - thus highlighting the threat to a Master en route into the area of risk. The IMB annual reports reproduce the piracy reports received by the piracy reporting centre. They define a piracy attack as

> An act of boarding or attempting to board any ship with the apparent intent to commit theft or any other crime with the apparent intent or capability to use force in the furtherance of that act. (IMB, 2009)

Under this definition, pirate attacks include all actual or attempted attacks on vessels while in port, anchored, berthed or underway. While there is some acknowledged under-reporting, it is the most complete database on maritime piracy that is available. We obtained the annual reports of piracy and robbery incidents from 1999-2010. Each report provides a detailed listing of the piracy incidence, containing the following information:

- Date (usually to day)
- Name of Ship
- Flag of Ship (sometimes)
- Call sign of ship (not always)

- IMO number of ship (not always)
- Information on location of attack, various levels of detail but mostly a geo-code.
- A narrative of the attack

In total, data on 5,456 incidents is reported. We were not able to use all observations, as quite often for attacks that take place near some ports or just off some islands, the report does not include a geo-coded location. We tried to make use of as many observations as possible by manually geo-coding the missing observations. Furthermore, in early years the data does not give information on whether the vessel was underway or at anchor when it was attacked. This data was manually extracted by analyzing the narrative of the attacks.

Using the maritime areas that we describe in the text, we arrive at a monthly number of piracy attacks in that particular maritime area. This time series is then used throughout the paper.

A.3 Wind and Seasonality of Attacks

The connection between windspeed and pirate risk is well-documented. For example, the Office of Naval Intelligence (ONI), a U.S. navy think tank, publishes the Piracy Analysis and Warning Weekly (PAWW) which uses weather data to predict piracy risks in the Somalia area.

We obtained wind data from the National Oceanic and Atmospheric Administration (NOAA), which, among others, provides detailed satellite and observational weather data for the world's oceans. For our purposes we accessed the NOAA Multiple-Satellite Blended Sea Winds database.[44] This particular database has the advantage that it is compiled from several satellites, which limits the number of coverage gaps. Another advantage is, that it provides the data on a fine spatial grid of $0.5°$ and is available, without gaps from 1987 onwards.

From this database we extracted the monthly mean wind speed pertaining to the geographical grid of our piracy regions. For each month, we have around 8,800 observations of the monthly mean wind speed per $0.5°$ cell

[44] The data can be accessed via `http://www.goo.gl/DM80l`.

corresponding to our grid. We use this to compute the average wind speed in any month for both the Somalia and Indonesia area.

Figure A1 shows the average monthly wind speed for the Somalia area (dotted line) and the predicted wind speed (solid line). The predicted wind speed is calculated from a regression of wind speed on month dummies

$$E\left[wind_t\right] = \sum_{m=1}^{12} month_m\left(t\right) + \epsilon_t.$$

This regression has an R^2 of 0.997. The strong seasonal pattern is also apparent in figure A1 which clearly shows the summer monsoon seasons with increased wind speeds and January and February with very calm winds.

Figure A2 shows the connection of the average wind speed prediction (lagged) and mean piracy attacks from Table 1. It shows that attacks and lagged wind speed are highly correlated. This is in line with UNOSAT (2010) where the lag reflects the latency period for the pirate militias to redeploy their vessels from the main militia bases along the Puntland coast.

A.4 Algorithm for Maritime Routes and Distances

We first determine start and end points for each journey. We use country start and end points rather than specific ports. This is because there is some ambiguity in the port information. This is more severe for some countries. For example, the United States has access to more than one Ocean so that errors could be quite large.

Each country information is interpreted as a specific position. We assigned the most frequently occurring port as our start and finish point for each country. We are then able to automate the way treatment is assigned by computing maritime routes between these points.

The algorithm proceeds as follows.

First, we transform a world map into a coarse 1° grid of the world. The coarseness of the grid allows us to compute optimal routes for the 1,600 routes in a reasonable amount of time on a standard desktop computer. The grid is thus a 360×180 matrix, which we can think of as a graph. Each cell in the matrix represents a node of the graph. We assume that vessels can travel into any of the 8 neighboring cells. The transformation into a grid takes into account that moving along a diagonal corresponds to a larger distance (i.e. higher costs) than moving along straight line vertices.

Second, we then assigned to each cell a cost of crossing using the map on which the grid was defined. We normalize this cost of crossing to be 1 for sea- or oceans and passing a very large number for landmass. We had to manually close the North-West passage manually and, due to the coarseness of the grid, we had to open up the Suez canal, the Malacca Straits and the Panama canal.

Third, the start- and end-locations, given as GPS coordinates, are then mapped into a particular cell in this graph. We can use simple shortest-path algorithms to compute an optimal path from any two points on the grid. The shortest-path implementation we used is a Dijkstra algorithm implemented in the R package Gdistance.[45]

The algorithm delivers three outputs: a shortest path as a sequence of GPS coordinates, its distance and a cost measure. We use the actual path for the intention to treat assignment that we describe in the text.

B Markov Chain Forecasts

B.1 Basics

Assume that attacks in region r at time t are given by the following "switching" model:

$$a_{rt} = \mu_{r\ell}\left(1-\delta\left(\ell_{rt}\right)\right)+\mu_{rW}\delta\left(\ell_{rt}\right)+\varepsilon_{rt} \quad \text{with } \varepsilon_{rt}\sim N(0,\sigma^2_{r\ell_{rt}}) \tag{12}$$

where $\delta\left(S\right)=0$ and $\delta\left(W\right)=1$. Thus, μ_{rS} is the mean number of attacks in the inactive state and μ_{rW} is the number of attacks when pirates are active. This allows for the possibility that $\mu_{rS}>0$. The transition matrix between states is given by:

$$\begin{array}{ccc} & \ell_{rt-1}=W & \ell_{rt-1}=S \\ \ell_{rt}=W & p_r & 1-q_r \\ \ell_{rt}=S & 1-p_r & q_r \end{array}$$

and state in region r at date t, follows the process:

$$\ell_{rt}=1-q_r+\lambda\ell_{rt-1}+v_{rt} \text{ where } \lambda_r=q_r+p_r-1$$

[45]The R package is available from `http://www.goo.gl/BCj6G`.

where v_{rt} is an error term with a state-contingent distribution of

$$v_{rt} \mid (\ell_{rt-1} = W) = \begin{cases} 1 - p_r & \text{with probability} \quad p_r \\ -p_r & \text{with probability} \quad 1 - p_r \end{cases}$$

and

$$v_{rt} \mid (\ell_{rt-1} = S) = \begin{cases} -(1 - q_r) & \text{with probability} \quad q_r \\ q_r & \text{with probability} \quad 1 - q_r. \end{cases}$$

The model has a vector of six region-specific parameters

$$\theta_r \equiv \left\{ \mu_{rW}, \mu_{rS,} \sigma^2_{rW}, \sigma^2_{rS}, p_r, q_r \right\}$$

which is a complete description of the parameters governing the process of piracy in region r. Most of our use of the model will turn around just three parameters from this vector: μ_{rW}, μ_{rS}, p_r and q_r

The history of attacks is used to estimate the probability $P(\ell_{rt} = W \mid H_{rt}, \theta_r)$ given the attack history H_{rt} and the parameter vector θ_r. (Details are provided below.) This probability can then be used to form expectations about the level of future attacks in region r, i.e. a_{rt+1}. It is easy to show that given equation (12) the estimate of attacks in the next month is

$$\begin{aligned} E(a_{rt+1} : H_{rt}) &= \mu_{rW}(1 - q_r) + \mu_{rS} q_r \\ &\quad + (\mu_{rW} - \mu_{rS}) \lambda_r P(s_{rt} = W \mid H_{rt}, \theta_r) \end{aligned} \tag{13}$$

where $\lambda_r \equiv p_r + q_r - 1$. The first two terms in equation (13) are time-invariant functions of the regional parameters θ_r. One can interpret them as the expected level of attacks in times of inactivity, i.e. at $P(s_{rt} = W \mid H_{rt}, \theta_r) = 0$. The second term shows that the expected violence in the next period only depends on the estimated probability of conflict in t, the differences in attacks between active and inactive months and the persistence, λ_r.

B.2 Estimation

A good starting point for the calculation of the probability of being in conflict, $P(\ell_{rt} = W \mid H_{rt}, \theta_r)$, is Bayesian updating in period t. In period t, the extrapolation of last period $P(\ell_{rt} = W \mid H_{rt-1}, \theta_r)$ is updated with attacks in t according to the standard formula:

$$P(\ell_{rt} = W \mid H_{rt}, \theta_r) = \frac{f(a_{rt} \mid \ell_{rt} = W, H_{rt-1}, \theta) P(\ell_{rt} = W \mid H_{rt-1}, \theta_r)}{\sum_{j=S}^{W} f(a_{rt} \mid \ell_{rt} = j, H_{rt-1}, \theta_r) P(\ell_{rt} = W \mid H_{rt-1}, \theta_r)}.$$

The immediate insight from this formula is that the probability can only be calculated with an estimate of θ_r because the conditional densities are given by

$$f\left(a_{rt} \mid \ell_{rt} = j, H_{rt-1}, \theta_r\right) = \frac{1}{\sqrt{2\pi\sigma_{rj}^2}} \exp\left(-\frac{\left(a_{rt} - \mu_{rj}\right)^2}{2\sigma_{rj}^2}\right)$$

and therefore depend on parameters in θ_r.

The probability $P\left(\ell_{rt} = W \mid H_{rt}, \theta_r\right)$ can be calculated if the past estimate $P\left(\ell_{rt-1} = W \mid H_{rt-1}, \theta_r\right)$ is known. To see that this dependency of $P\left(\ell_{rt} = W \mid H_{rt}, \theta_r\right)$ on $P\left(\ell_{rt-1} = W \mid H_{rt-1}, \theta_r\right)$ note that

$$P\left(\ell_{rt} = W \mid H_{rt}, \theta_r\right) = \sum_{j=0}^{1} P\left(\ell_{rt} = W, \ell_{rt-1} = j \mid H_{t-1}, \theta_r\right).$$

and

$$P\left(\ell_{rt} = W, \ell_{rt-1} = j \mid H_{t-1}, \theta_r\right) = P\left(\ell_{rt} = 1 \mid \ell_{rt-1} = j\right) P\left(\ell_{rt-1} = W \mid H_{rt-1}, \theta_r\right)$$

where $P\left(\ell_{rt} = W \mid \ell_{rt-1} = j\right)$ is nothing else than the estimated p_r and $1 - q_r$ contained in θ_r. Hence, one needs $P\left(\ell_{rt-1} = W \mid H_{rt-1}, \theta_r\right)$ to calculate $P\left(\ell_{rt} = W \mid H_{rt}, \theta_r\right)$.

This reliance of $P\left(\ell_{rt} = W \mid H_{rt}, \theta_r\right)$ on $P\left(\ell_{rt-1} = W \mid H_{rt-1}, \theta_r\right)$ implies that previous probabilities of conflict have to be calculated first. The filter therefore takes a starting value $P\left(\ell_{r0} = 1 \mid H_{r0}, \theta_r\right)$ and calculates

$$P\left(\ell_{r1} = 1 \mid H_{r1}, \theta_r\right), P\left(\ell_{r2} = 1 \mid H_{r2}, \theta_r\right) ... P\left(\ell_{rT} = 1 \mid H_{rT}, \theta_r\right)$$

by iteratively updating the probability of conflict with the monthly attacks data a_{rt}. To some degree this is what the charter parties of a shipment through region r would have done, too.

However, this simple filter relies on the availability of the vector θ_r. The problem is that θ_r cannot be calculated without knowing the states $\ell_{r1}, \ell_{r2} ... \ell_{rT}$ which are unobserved. Hence, the estimation method needs to determine when regime shifts occurred and at the same time estimate the parameters of the model. One way of estimating the parameters of the violence process is the Expectation Maximization (EM) Algorithm described in Hamilton (1990) which generates an estimate of θ_r by iteration.

In each iteration the algorithm makes use of the "smoothed" probability of conflict which is based on the entire violence data for a region

$$P\left(\ell_{rt} = 1 \mid a_{rT}, a_{rT-1}, ..., a_{r1}, \theta_r\right).$$

C Cost Factors

C.1 Damage to Vessels

Direct damage is typically due to attempts to board a vessel. This could be damage due to small arms fire or rocket propelled grenades. Damages to the cargo are typically small, at least in bulk shipping which we focus on, while damage to the hull is more common.[46] As a consequence, the risk to hulls has now been unbundled from the Hull and Machinery (H&M) insurance and put into special War Risk Insurance. The War Risk Insurance is typically an annual police, but additional premiums are charged if vessels travel through high risk areas. These premiums are passed on to the charterers. In May 2008 the Joint War Committee, an advisory body set up by the maritime underwriters based in London, declared the Gulf of Aden to be an area of high risk for which these additional premiums apply. The high risk area has since then expanded considerably and now covers the whole area called "Somalia" in Figure 1.[47] Cargo insurances do not typically charge additional premiums for specific sea areas.[48] Since hull damage is covered by insurance we expect such costs to be passed on to ship charterers.

C.2 Loss of Hire and Delay

The distribution of costs coming from loss of hire depends on the individual chartering agreements. These determine to what extent a charterer has to pay the daily chartering rate for the time that a ship is being held by pirates. According to an industry norm the charterer is responsible for the first 90 days following seizure.[49] With an estimated rolling average of 205 days under seizure at the end of 2010 this implies a relatively even share of costs.[50] The risk of not being operational after release (due to damage to ship during captivity) is with the ship owner. This risk is substantial as immobility of several months without maintenance is bound to incapacitate a ship.

[46] Hastings (2009) stresses that cargo is not stolen during captivity in the case of Somalia because the infrastructure for transporting it off is lacking.

[47] For details see `http://www.goo.gl/MOg7S`.

[48] See Marsh's Global Marine Practice available at `http://www.goo.gl/vhXoJ`.

[49] This norm is the "BIMCO Piracy Clause 2009". BIMCO is the largest international shipping association representing ship-owners.

[50] For a summary see MARSH (2011).

C.3 Ransom Payments

Ransom payments and the costs of negotiators typically reach several million dollars and are, in principle, shared between the owner of the vessel, a chartering party and the owner of the cargo or special insurances that these parties purchased.[51] However, this applies only on journeys with cargo on board. In addition, the crew falls into the ship owners obligations if brought off the ship.[52] Both the ship owner's H&M insurance and the war risk insurance will cover part of this ransom. Kidnap and Ransom (K&R) insurance policies, introduced in 2008, provide additional cover for the payment of ransoms. It is unclear what proportion of ships are insured by these policies.[53] However, the fact that these are designed for shipowners is indicative that these bear the main burden of ransom payments.

Even if ransoms are not paid, ship-owners need to pay a significant wage risk bonus to crew when travelling through pirate territory. According to the International Maritime Employers' Council (IMEC) seafarers are entitled to a compensation amounting to 100% of the basic wage on each day a vessel stays in a high risk area.

C.4 Security

The maritime industry's Best Practices manual lists a long list of changes to ship and crew stretching from barbed wire, high pressure fire hoses and citadels to additional security teams, that can help prevent a successful pirate attack/hijack.[54] All these expenses will be borne by the ship owner. The notion of an "arms race" between better equipped pirates and ever more sophisticated defence mechanisms by ship owners suggests that there might be costs on the side of ship owners that exceed the expected sum of ransom payments. According to *The Economist* newspaper, some 40% of ships carried security crews by 2012.[55] Conversations with industry experts suggest that the price per security crew of four is fixed and does not generally vary with

[51] See `http://www.goo.gl/jSO3f`.

[52] For a discussion see MARSH (2011) and `http://www.goo.gl/vhXoJ`, accessed on 10.04.2012.

[53] Though some industry experts claim that as of 2009, the proportion of ships covered by such policies was less than 10 %, see `http://www.goo.gl/Uh3zX`.

[54] These are updated regularly. The version referred to here is BMP4 (2011) "Best Management Practices for Protection against Somalia Based Piracy".

[55] *Laws and guns*, The Economist, April 14th 2012.

the type of ship under consideration. The quoted price we work with in the paper is 3000 USD per day for a crew of four.

C.5 Re-routing

The cost of re-routing around the Cape of Good Hope, especially among very large vessels, has been highlighted as a major element of the costs of piracy in early publications on the issue.[56] In the public debate this notion was often supported by a drastic decrease in Suez canal traffic in 2008. However, Suez canal traffic data can be misleading in this regard as world bulk trade collapsed only a few months before the increase in pirate activity. In addition, it should be kept in mind that large Capesize Bulk Carriers were never able to cross the Suez canal and would go around the Cape regardless of pirate activity. Indeed, more recent evidence using satellite imaging suggests that re-routing around the Cape is likely to be a minor issue.[57] Rerouting costs are in principle fully recoverable from the charterer since contracts are written for daily ship hire and any increase in fuel costs can be passed on.

The bottom line from this discussion is that looking at contract prices in shipping should pick up a good deal of the increased costs imposed by piracy. However, we would expect this to be a lower bound on the overall cost to the shipping industry since some of the direct costs paid by charterers may not be captured. This issue is taken into account in our welfare calculations.

D Welfare Cost Calculations

D.1 Basic Estimate

The first column in Table 5 reports:

$$L^1(\Delta) = [\Delta - \tau(\Delta)]\,\nu\hat{X}\,(\psi + \nu\,[c + \Delta])\,.$$

In this appendix, we first present the calculations for column (1) in Panel (A) and (B). We then discuss the calculations of column (2) and (3).

[56] See, for example, One Earth Future (2010) and Bendall (2011).
[57] See One Earth Future (2011).

Total Cargo shipped through the Suez Canal is around $646,064,000$ tons per year.[58] According to data from Stopford (2009) bulk ships travel at around 26km per hour (14 knots) and the average distance that charters travel which pass through the Gulf of Aden is $16,400$ km with a typical charter length of 26.3 days. To this we add 4 days on charter for loading and unloading. This does not include waiting time in Suez and neglects the possibility of re-routing.

Our estimates in Panel B in Table 5 add the costs imposed by piracy on maritime traffic through the broader Somali area to this cost. In order to calculate this we use the estimates in column (6) of Table 3. In order to give a number to the tonnage travelling through this area (but not the Gulf of Aden) we use COMTRADE data on commodity trade between the Middle East and Africa/Asia (excluding India).[59] The data suggests that about $578,000,000$ tons were shipped through the area in 2010. Most of this is oil exports from the Middle East. As before, we use our data to calculate the average charter length (20.67 days) and the average charter rate (0.4646 USD/DWT days).

Low estimate:
Gulf of Aden:

$$\begin{aligned}0.00572 * 14.33 * 0.4726 * 30.3 * 646064000 &= 758 \text{ million USD}\\ &\quad -120 \text{ million USD}\\ &= 638 \text{ million USD}\end{aligned}$$

Somalia:

$$\begin{aligned}0.0066 * 14.33 * 0.4726 * 30.3 * 646064000 &= 875 \text{ million USD}\\ 0.00226 * 14.33 * 0.4648 * 20.67 * 578000000 &= 180 \text{ million USD}\\ &\quad -120 \text{ million USD}\\ &= 935 \text{ million USD.}\end{aligned}$$

[58] See http://www.goo.gl/J3lGl.

[59] For this we define two groups of countries and calculate total tons of trade between the two groups. A) Middle Eastern countries: Bahrain, Iran, Iraq, Kuwait, Oman, Pakistan, Qatar, Saudi Arabia, United Arab Emirates; and B) Africa/Asia: Angola, Australia, Bangladesh, Cambodia, China, Hong Kong SAR, Macao SAR, Dem. People's Rep. of Korea, Fmr Dem. Rep. of Vietnam, Fmr Rep. of Vietnam, Indonesia, Japan, Kenya, Madagascar, Malaysia, Mozambique, Myanmar, Nepal, New Zealand, Philippines, Rep. of Korea, Singapore, South Africa, Sri Lanka, Thailand, United Rep. of Tanzania, Viet Nam.

High estimate:

Our high estimate uses the estimate on the dummy on war area risk from Table 3 to derive the costs of piracy. That estimate suggests that piracy leads to an increase of charter rates by 12.9%.
Gulf of Aden:

$$\begin{aligned} 0.129 * 0.4726 * 30.3 * 646064000 &= 1,193 \text{ million USD} \\ & \quad -120 \text{ million USD} \\ &= 1,073 \text{ million USD} \end{aligned}$$

Somalia: we use estimates from a regression which we have not reported. It gives estimates of 0.163 for the Gulf of Aden and 0.08 for non-Gulf of Aden trade lanes. Thus:

$$\begin{aligned} 0.145 * 0.4726 * 30.3 * 646064000 &= 1,342 \text{ million USD} \\ 0.075 * 0.4648 * 20.67 * 578000000 &= 416 \text{ million USD} \\ & \quad -120 \text{ million USD} \\ &= 1,638 \text{ million USD.} \end{aligned}$$

Column (2) in Table 5 applies the additional factor derived in equation (10). Details are in the following section.

D.2 Quantity Effects

Formula for $L^2(\Delta)$ The general formula for the welfare loss can be written

$$\begin{aligned} V(\psi + \nu[c+t]) - V(\psi + \nu[c+\Delta]) &= Q(t) \\ &\simeq Q(\Delta) + Q'(\Delta)[t-\Delta] + \frac{1}{2}Q''(\Delta)[t-\Delta]^2 . \end{aligned}$$

Note that

$$V(\psi + \nu[c+t]) = U\left(\hat{X}(\psi + \nu[c+t])\right) - \hat{X}(\psi + \nu[c+t])[\psi + \nu[c+t]] .$$

When we derive the partial derivative using

$$\frac{\partial U\left(\hat{X}(\psi + \nu[c+t])\right)}{\partial \hat{X}(\psi + \nu[c+t])} = \psi + \nu[c+t]$$

we find that

$$Q'(t) = -\upsilon \hat{X}(\psi + \nu [c+t]).$$

Now observe that:

$$\begin{aligned} Q(\Delta) &= 0 \\ Q'(\Delta) &= -\nu \hat{X}(\psi + \nu [c+\Delta]) \\ Q''(\Delta) &= -\nu^2 \hat{X}'(\psi + \nu [c+\Delta]) \end{aligned}$$

We assume that the demand function has a constant price elasticity η so that we can write

$$\hat{X}(\psi + \nu [c+t]) = (\psi + \nu [c+t])^{-\eta}.$$

and inserting all this we get an approximation of the welfare loss

$$\begin{aligned} & Q(\Delta) + Q'(\Delta)[t-\Delta] + \frac{1}{2} Q''(\Delta)[t-\Delta]^2 \\ = \; & \nu \hat{X}(\psi + \nu [c+\Delta])[\Delta - t] - \frac{1}{2}\nu^2 \hat{X}'(\psi + \nu [c+\Delta])[t-\Delta]^2 \\ = \; & \nu \hat{X}(\psi + \nu [c+\Delta])[\Delta - t]\left[1 + \frac{1}{2}\eta \frac{\nu(\Delta - t)}{\psi + \nu [c+t]}\right] \\ = \; & \nu \hat{X}(\psi + \nu [c+\Delta])[\Delta - t]\left[1 + \frac{1}{2}\hat{\eta}\frac{\Delta - t}{c+\Delta}\right] \\ \geq \; & \nu \hat{X}(\psi + \nu [c+\Delta])[\Delta - \tau(\Delta)]\left[1 + \frac{1}{2}\frac{\Delta - \tau(\Delta)}{c+\Delta}\hat{\eta}\right] \end{aligned}$$

where we have replaced the trade elasticity with regard to price η (which we do not have) with the trade elasticity with regard to transport costs, $\hat{\eta}$ (available from the trade literature). Observe that the trade elasticity with respect to transport costs, $\hat{\eta}$, in terms of our model is

$$\hat{\eta} = \frac{\partial \log X}{\partial \log \phi} = \eta \frac{\phi}{\psi + \phi}$$

so that, using the definition of ϕ above, we get

$$\eta = \hat{\eta}\frac{\psi + \nu [c+\Delta]}{\nu [c+\Delta]}.$$

The last approximation uses the fact that $\tau(\Delta) \leq t$. So this gives a lower bound on the welfare loss and depends on observables. Comparing this to equation (9) we have that

$$L^2(\Delta) \simeq L^1(\Delta)\left[1+\frac{1}{2}\frac{\Delta-\tau(\Delta)}{c+\Delta}\hat{\eta}\right].$$

Implementation In the low estimate the relative increase in transport costs due to piracy is

$$\frac{\Delta}{c+\Delta} = 0.00572 * 14.33 = 0.082$$

while in the high estimate it is

$$\frac{\Delta}{c+\Delta} = 0.129.$$

We use four different estimates for $1-\frac{\tau(\Delta)}{\Delta}$. The low Gulf of Aden estimate is

$$1-\frac{\tau(\Delta)}{\Delta} = 1-\frac{120 \text{ million USD}}{758 \text{ million USD}} = 0.84$$

the other estimates are calculated analogously.

There are several possible numbers we could use for $\hat{\eta}$. Latest results from Feyrer (2009) who uses the Suez Canal closure as a shock to distance and calculates the effects on trade from distance costs suggests that an estimate between 0.2 and 0.5 for $\hat{\eta}$ is realistic. The estimate found in a meta study in Disdier (2008) is 0.9. Given the similarity of the Feyrer study we use the estimate of 0.5 in column 2. This leads to an adjustment of

$$\begin{aligned} L^2(\Delta) &= L^1(\Delta)\times\left[1+\frac{1}{2}\left(1-\frac{\tau(\Delta)}{\Delta}\right)\frac{\Delta}{c+\Delta}\hat{\eta}\right] \\ &= L^1(\Delta)\times 1.0172 \end{aligned}$$

for the low estimate in the Gulf of Aden. This is applied to the whole welfare loss caused by price increases. For the low estimate in the Gulf of Aden this is

$$(758 \text{ million USD} - 120 \text{ million USD}) \times 1.0172 = 650 \text{ million USD}.$$

D.3 Insurance Averaging

The general average insurance rules imply that the cost of piracy is borne by both cargo owners as well as by the ship owners. It is the ship owners, who in turn pass on this cost to the chartering parties in form of higher chartering rates. This is what we estimate in our main specification. However due to the general average principle, this effect is underestimated, since the ship owner's insurer pays only a share of the piracy cost in cases in which the ship is laden. In this appendix we describe at how we arrive at the scaling factor $\zeta > 1$ used in the welfare estimates shown in the main text (Table 5).

The first step is to estimate the market value of the vessels in our dataset. Second, we estimate the values of the cargo that these ships transport. The ratio of the values is indicative for general average rules. In a third step, we estimate the share of ballast journeys, in order to correct for the fact that, during these journeys, the ship owner bears the entire cost of piracy.

From weekly market reports of the ship brokerage firm Intermodial[60], we obtained recorded sales of dry bulk vessels on the second hand market for 2010. In total, there were 402 recorded transactions. For a subset of 379 of these transactions, we know the age of the ship, the vessel's deadweight tonnage and the value of the transaction. Using these data on transactions, we can estimate the value of the ships 2010 in our dataset for the year. These estimates use two common controls in both data-sets: the age of ship and its tonnage to carry out this matching. Clearly, there are many more controls that correlate with the price that a vessel achieves on the market. However, we abstract from these due to data limitations. Either way, our estimated values are likely constitute a lower bound on a ship's value due to the standard adverse selection problem.

Using the 379 recorded sales, we estimate a regression of the form:

$$\text{ShipPrice}_l = \beta_0 + \beta_1 Age_l + \beta_2 DWT_l + \epsilon_l$$

Using the estimated coefficients, we generate fitted values for our main sample for the ships in 2010. The estimated values for vessels travelling through the Suez Canal in our sample are as follows:

[60] These reports can be accessed on `http://www.goo.gl/RmUZU`.

Quartile	Value (USD)
Lower Quartile	26,791,260
Median	32,637,280
Upper Quartile	37,281,280

This compares well with industry-wide figures published by ship brokerage firms. For 2010, Intermodal for example reports that a five year old Panamax vessel with 75,000 tons deadweight was estimated to be worth 39 Million USD. In our dataset, the median ship on the Aden route is 7 years old, i.e. slightly older and with 73,726 tons deadweight slightly smaller. This makes us confident that the fitted ship values are indeed reasonably realistic for 2010.

We estimate the value of the cargo carried by the dry bulk ships in our sample using Suez Canal traffic statistics. These provide a very crude disaggregation into the different types and quantities of goods carried through the Suez Canal. We try to link this disaggregation with average commodity price data for the year 2010 obtained from the IMF and the World Bank. Any matching to these average commodity values is quite crude since the Suez authorities, for example, do not decompose such broad categories as cereals, ores and metals, coal and coke or oil seeds.[61] With this caveat, we match to our data using four main commodity prices: coal, iron ore, soybean and wheat. Using the traffic statistics on these four broad commodities, we compute the value of the average ton of these commodities passing through the Suez canal.

Using this, we estimate the value of the average ton of dry bulk carried through the Suez Canal. Using the median ship in our dataset, this allows us to estimate the value of cargo. We compute lower- and upper-bound values for these estimates using plain commodity prices for coal and wheat. This yields the following range of estimates:

Cargo type	Price (USD) per Ton	Cargo Value (USD)
(Low value) Coal cargo	106.03	7,451,675.41
Average Suez dry bulk cargo	165.97	11,663,908.20
(High value) Wheat	223.67	15,719,087.90

[61] These four commodities make up at least 48.3 % of all commodities in the Suez traffic that can broadly be classified as (dry) bulk cargo.

Using these estimates, we can compute the ratio of the cargo to ship value. However, using this share as a scaling factor ζ, without correcting for the share of ballast (i.e. without cargo) journeys, we are likely to underestimate the general average share paid by the ship owner. Using Suez canal traffic data, we find that, in 2010, 25.7% of the dry bulk carrier transits were ballast journeys. Hence, the general average share of the ship owner is:

$$\zeta = (1-b)(1-\text{cargo/ship}) + b$$

where b is the share of the journey in ballast.

Using this, we arrive at the following general average shares for our median ship value:

Cargo type	Cargo-to-ship value	ζ
Average Suez dry bulk cargo	0.35738	0.7346

The value of ζ from this table is used in the Table 5 to estimate the welfare loss.

This implies that $L^1(\Delta)$ can underestimate the welfare cost by a factor of up to 2.13. Combined with our high estimate this would imply an increase in chartering cost by 27%. However, for reasons laid out in section 2.3 this is likely to be an upper bound. The low estimate for Aden, for example, can then be calculated as

$$\begin{aligned} & 758 \text{ million USD } \times 2.13 \\ & -120 \text{ million USD} \\ = \; & 1,495 \text{ billion USD.} \end{aligned}$$

This is the figure reported in Table 5.

Table 1: Seasonality in Attacks in Somalia Region

month	before May 2008	after May 2008
January	1.5	12.5
Februar	2.7	7.5
March	2.9	31.5
April	5.2	34.1
May	3.7	21.0
June	1.8	10.5
July	3.5	4.6
August	2.1	9.4
September	1.3	14.6
October	3.8	18.7
November	2.2	28.0
December	2.4	12.6
average	2.8	17.1
difference (after-before)		14.3

Table 2: Main Results

VARIABLES	(1) daily charter rate per DWT	(2) daily charter rate per DWT	(3) daily charter rate per DWT	(4) daily charter rate per DWT
number of attacks (Somalia)	0.00572***	0.00589***	0.00257***	
	(0.00128)	(0.00130)	(0.000901)	
number of attacks (Indonesia)	0.000178	0.000443	0.00234	0.000191
	(0.00120)	(0.00120)	(0.00336)	(0.00119)
attacks * handysize (Somalia)				0.00335
				(0.00283)
attacks * handymax (Somalia)				0.00665***
				(0.00199)
attacks * panamax (Somalia)				0.00597***
				(0.00136)
attacks * small capesize (Somalia)				0.00637***
				(0.00189)
attacks * capesize (Somalia)				0.00206
				(0.00221)
ballast bonus per DWT		-8.07e-06		
		-5.14E-06		
ship age		-0.00614***		
		(0.000789)		
handysize	0.623***	0.637***	0.607***	0.621***
	(0.0224)	(0.0203)	(0.0369)	(0.0255)
handymax	0.401***	0.402***	0.354***	0.394***
	(0.0218)	(0.0203)	(0.0312)	(0.0257)
panamax	0.149***	0.150***	0.151***	0.153***
	(0.0142)	(0.00913)	(0.0222)	(0.0154)
capesize	-0.0385	-0.0514*	-0.0900	-0.0245
	(0.0398)	(0.0306)	(0.0883)	(0.0486)
route fixed effect	yes	yes	yes	yes
month fixed effect	yes	yes	yes	yes
Observations	24,363	24,332	10,058	24,363
R-squared	0.873	0.877	0.861	0.874

Notes: Standard errors in parentheses. Standard errors are clustered at the route level. *** p<0.01, ** p<0.05, * p<0.1. "DWT" is deadweight tonnage. "Daily charter rate per DWT" is the log of the time charter rate per day per deadweight tonnage. All attack variables are interactions between a dummy that indicates whether a ship will cross a pirate territory and the number of attacks in that territory. "Handysize" is a dummy that indicates ships with DWT<35000. "Handymax" are ships with 35000<DWT<55000. "Panamax" are ships with 55000<DWT<80000. "Small capesize" are ships with 80000<DWT<150000 (omitted). "Capesize" are ships with DWT>150000. "Ballast bonus" is a payment that compensates the ship owner for travelling without cargo on return. Column (3) only uses data after the surge in piracy in the Somalia region May 2008. Column (4) controls for interactions between ship categories and the respective region dummy.

Table 3: Robustness

VARIABLES	(1) daily charter rate per DWT	(2) daily charter rate per DWT	(3) daily charter rate per DWT	(4) daily charter rate per DWT	(5) daily charter rate per DWT	(6) daily charter rate per DWT	(7) daily charter rate per DWT	(8) daily charter rate per DWT
forecast number of attacks (Somalia)	0.00786***	0.0103***						
	(0.00175)	(0.00273)						
forecast number of attacks (Indonesia)	0.000595	0.00437						
	(0.00296)	(0.00285)						
number of attacks (Somalia)			0.00590***	0.00378***			0.00673***	0.00580***
			(0.00129)	(0.000928)			(0.00160)	(0.00151)
number of attacks (Indonesia)			0.00038	-0.00129			0.00108	0.000490
			(0.00120)	(0.00120)			(0.00140)	(0.00126)
annual GDP growth start region			0.0236*					
			(0.01159)					
annual GDP growth end region			-0.0047					
			(0.01375)					
number of attacks (Gulf of Aden)					0.0100***			
					(0.00244)			
number of attacks (Malacca)					-0.00177			
					(0.00203)			
Somalia number of attacks (route through Gulf of Aden)						0.00660***		
						(0.00146)		
Somalia number of attacks (route not through Gulf of Aden)						0.00226**		
						(0.000894)		
Indonesia number of attacks (route through Malacca Strait)						0.000250		
						(0.00130)		
Indonesia number of attacks (route not through Malacca Strait)						0.00248		
						(0.00225)		
ship size controls	yes	yes	yes	yes	yes	yes	yes	yes
route fixed effect	yes	yes	yes	yes	yes	yes	yes	yes
month fixed effect	yes	yes	yes	yes	yes	yes	yes	yes
region time trend	no	no	no	yes	no	no	no	no
Observations	24,363	24,363	24332	24,363	24,363	24,363	24,363	24,363
R-squared	0.873	0.873	0.877	0.878	0.873	0.874	0.873	0.873

Notes: Standard errors in parentheses. Standard errors are clustered at the route level. *** p<0.01, ** p<0.05, * p<0.1. "DWT" is deadweight tonnage. "Daily charter rate per DWT" is the ln of the time charter rate per day per deadweight tonnage. All piracy variables are interactions between a dummy that indicates whether a ship will cross a pirate territory and the number of attacks for that territory. "Forecast number of attacks" is the forecasted number of attacks next month calculated using an AR(2) model in column (1) and a Markov chain model for column (2). Column (4) controls for a seperate time trend for each start region. Column (5) takes a smaller treatment area and uses piracy estimates from attacks in this area. Column (6) uses the piracy estimates from our main specification and applies them to shipments though different areas. Columns (7) and (8) use the following treatment assignment: alternative routes not using the Suez canal were used if the alternative route was at most 10% and 20% longer than the Suez route, respectively.

Table 4: Extended Results

VARIABLES	(1) Suez Canal cargo traffic	(2) Suez Canal cargo traffic	(3) average ship size	(4) daily charter rate per DWT	(5) daily charter rate per DWT
number of attacks (Somalia)	-359.3***	-32.89	-16.99		
	(87.17)	(36.90)	(56.72)		
number of attacks (Indonesia)			202.9		
			(132.8)		
cargo traffic break		-20801***			
		(867.8)			
war risk area (Somalia)				0.129***	0.363***
				(0.0314)	(0.0957)
war risk area (Indonesia)				0.0405***	0.0232
				(0.0129)	(0.102)
war risk area * windspeed (Somalia)					-0.0362***
					(0.0120)
windspeed (Somalia)					0.00275
					(0.0168)
war risk area * windspeed (Indonesia)					0.00705
					(0.00520)
windspeed (Indonesia)					-0.0299
					(0.0199)
ship size controls	-	-	-	yes	yes
rote fixed effect	-	-	yes	yes	yes
month fixed effect	*	*	yes	yes	yes
Observations	108	108	12,753	24,363	24,363
R-squared	0.611	0.94	0.482	0.874	0.874

Notes: Standard errors in parentheses. Standard errors are clustered at the route level in columns (4) and (5). *** p<0.01, ** p<0.05, * p<0.1. Columns (1) and (2) use monlty time-series data from the Suez canal. Column (3) uses all data but aggregates by dyad. "Suez canal cargo traffic" is measured in DWT. "Average ship size" is the dyad average for that month in deadweight tons. "DWT" is deadweight tonnage. "Daily charter rate per DWT" is the ln of the time charter rate per day per deadweight tonnage. "Cargo traffic break" is a dummy variable that takes a value of 1 after the volume in trade through the Suez canal collapses in November 2008. All piracy variables are interactions between a dummy that indicates whether a ship will cross a pirate territory and the number of (expected) attacks in that territory. "War risk area" is a dummy that indicates whether an area was put defined as a war risk area by the Joint War Comittee. "Windspeed" is the (predicted) monthly windspeed in the piracy area in the same month. (*) Columns (1) and (2) control for a linear time trend.

Table 5: The Welfare Cost of Piracy in 2010

Panel A: Gulf of Aden	(1) L1 (in million USD)	(2) L2 (in million USD)	(3) L3 (in million USD)
low estimate	638	650	1495
high estimate	1073	1105	2422

Panel B: Somalia	(1) L1 (in million USD)	(2) L2 (in million USD)	(3) L3 (in million USD)
low estimate	935	953	2127
high estimate	1638	1687	3625

Calulcalations are discussed in section 4 and the appendix D. Column (2) adjusts the welfare loss by taking into account the change in trade. Column (3) adjusts the cost to take into account the share of costs borne by charterers. Panel B uses data on trade to and from the Middle East to calculate the costs for the area including the Indian Ocean.

Table A1: Summary Statistics

Variable	Mean	Std. Dev.	Min	Max
deadweight tonnage (DWT)	80092.19	39495.48	5169	300000
rate per day per DWT (in USD)	0.45	0.30	0.01	4.04
number of attacks in Somalia	7.03	9.06	0	42
number of attacks in Indonesia	6.08	3.93	1	23
ballast bonus per DWT (in USD)	1.03	70.26	0	1.10E+04
distance (in km)	8014	6846	0	2.41E+04
shipage (in years)	9.45	7.31	0	39
average predicted wind speed in m/s (Somalia)	6.34	1.38	4.36	8.81
average predicted wind speed in m/s (Indonesia)	5.80	0.57	4.69	6.58
forecast number of attacks Somalia (AR(2))	14.59	13.75	1.98	57.26
forecast number of attacks Indonesia (AR(2))	7.20	2.36	3.64	17.18
forecast number of attacks Somalia (Markov Chain)	7.73	5.22	2.79	14.20
forecast number of attacks Indonesia (Markov Chain)	5.74	1.94	4.13	8.62

Figure 1: Attacks and Treatment Areas

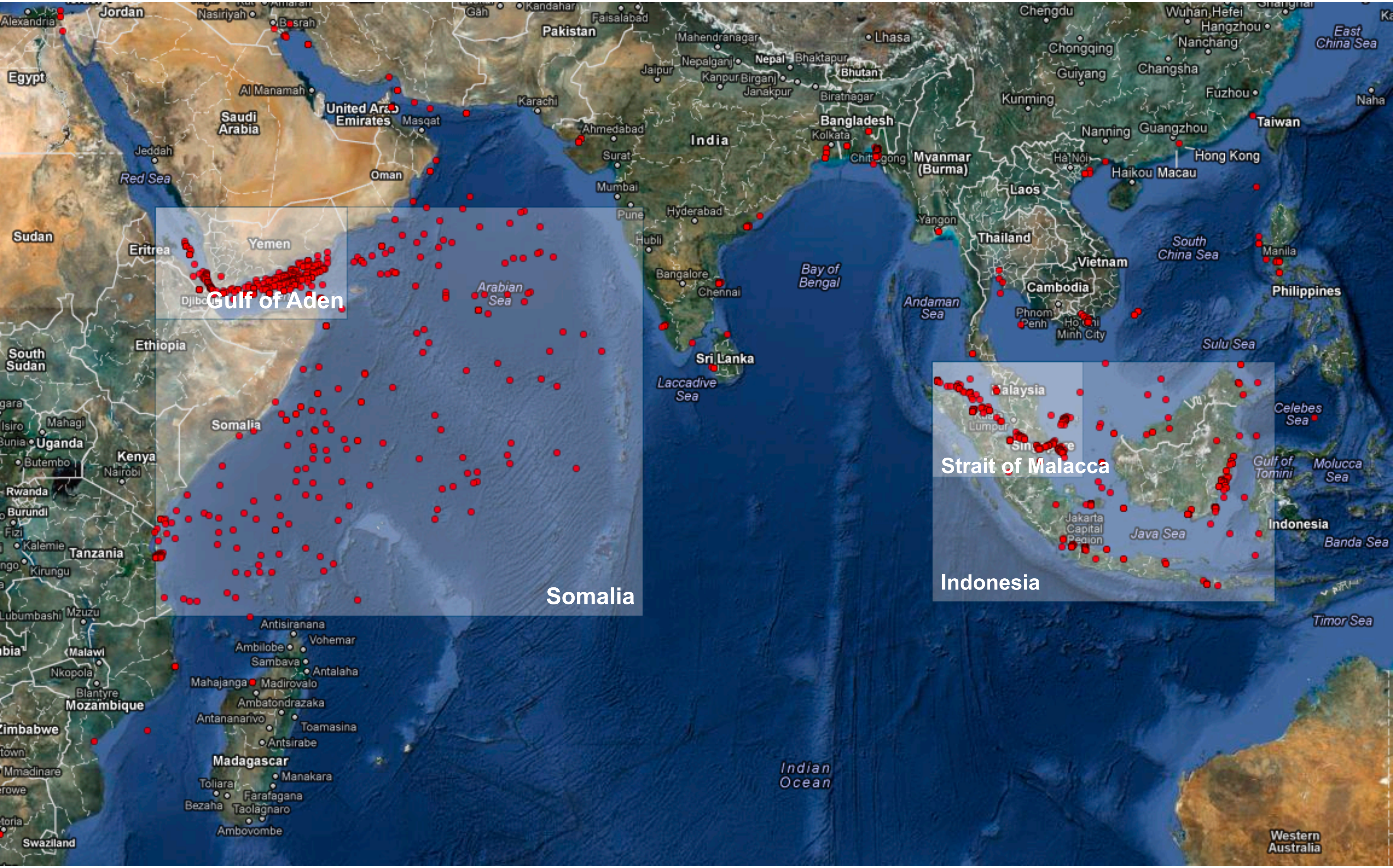
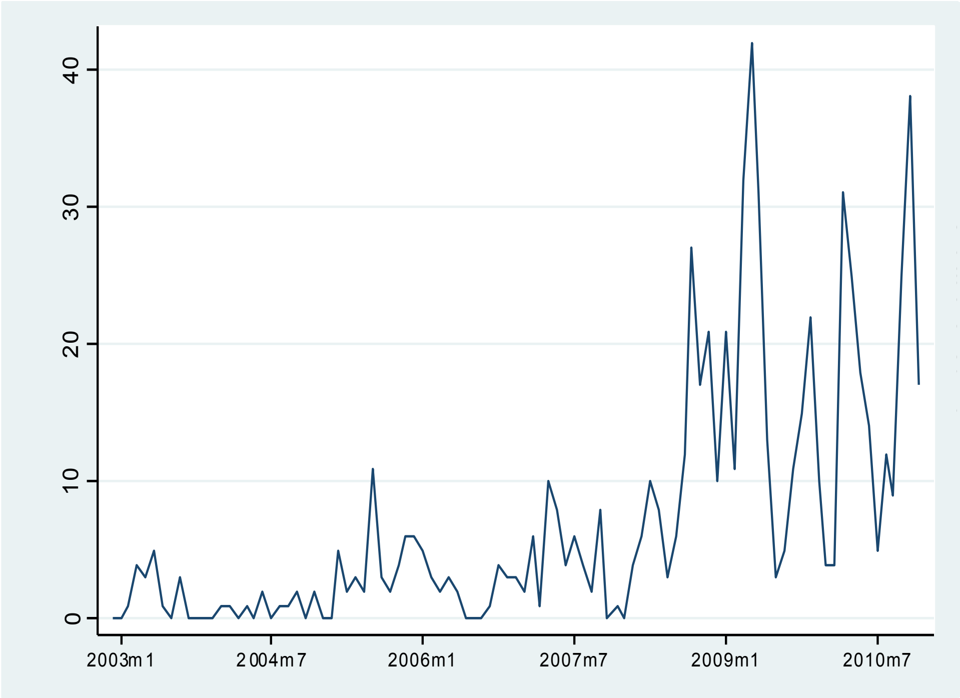


Figure 2: Time Series of Attacks in Somalia (left) and Indonesia (right)

Somalia



Indonesia

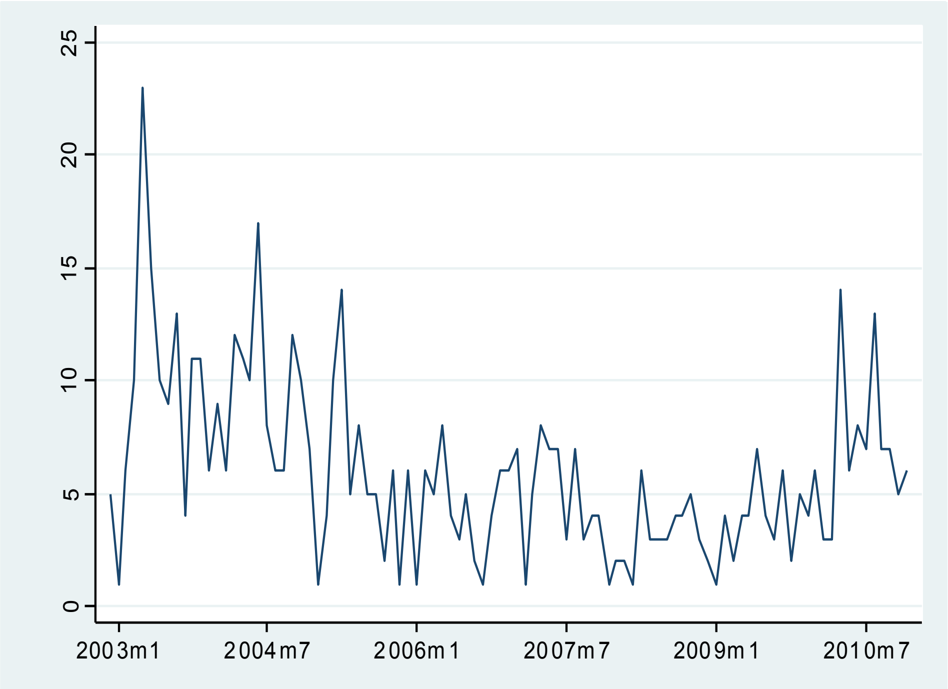


Figure 3: Calculated Shipping Lanes

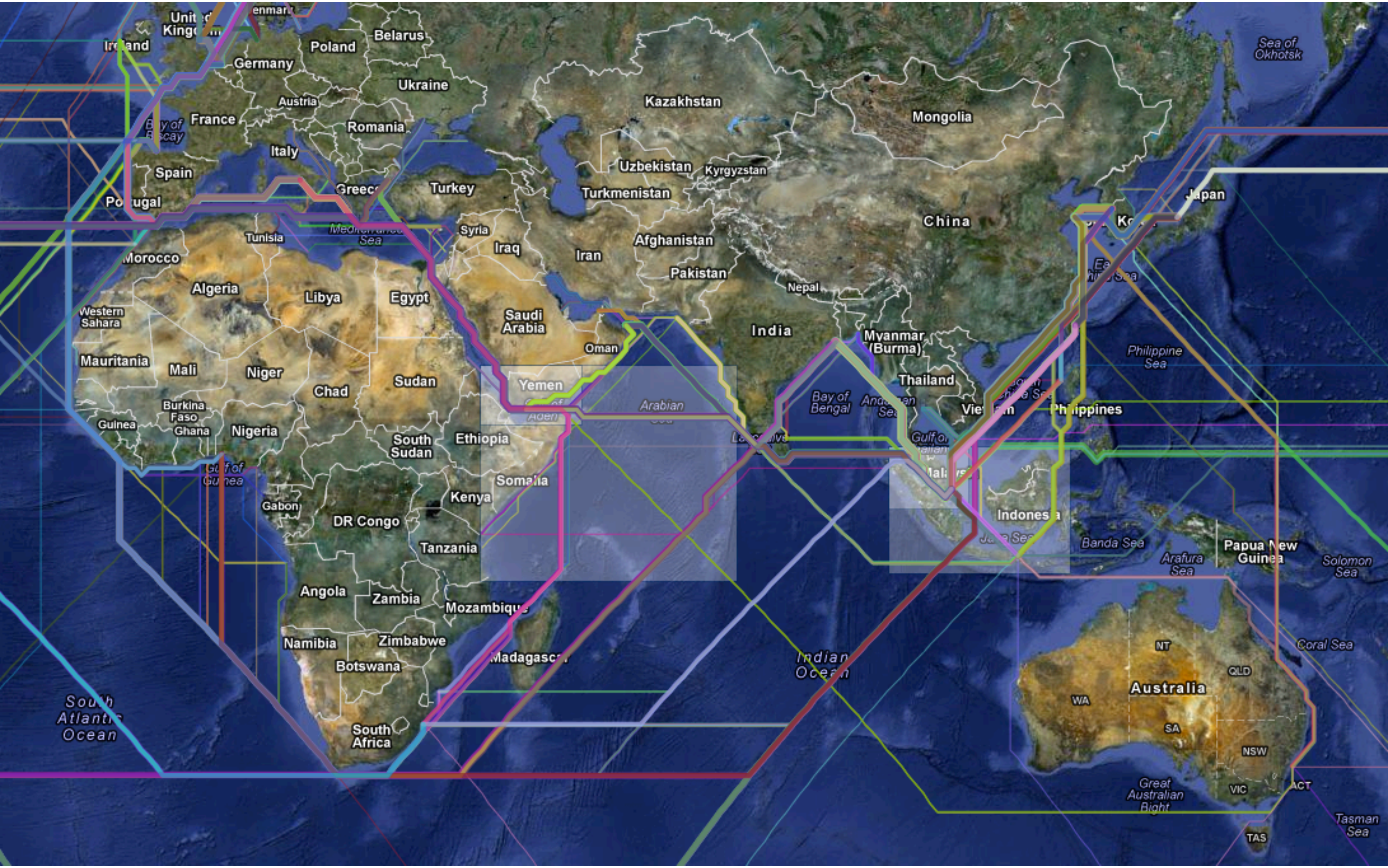


Figure 4: Shipping Cost Prediction of Pirate Activity and Wind Speed

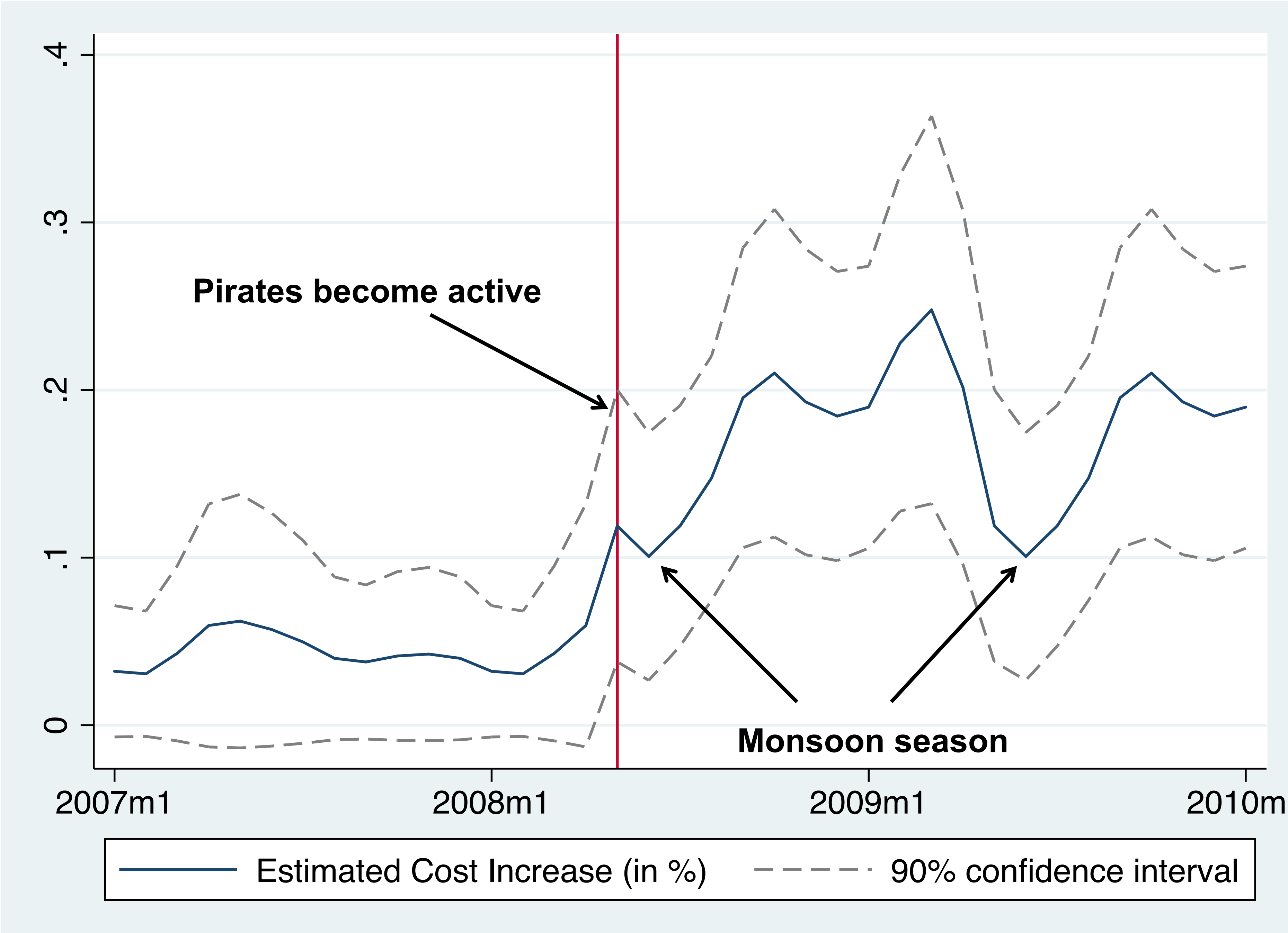


Figure A1: Wind Speed in the Somalia Area

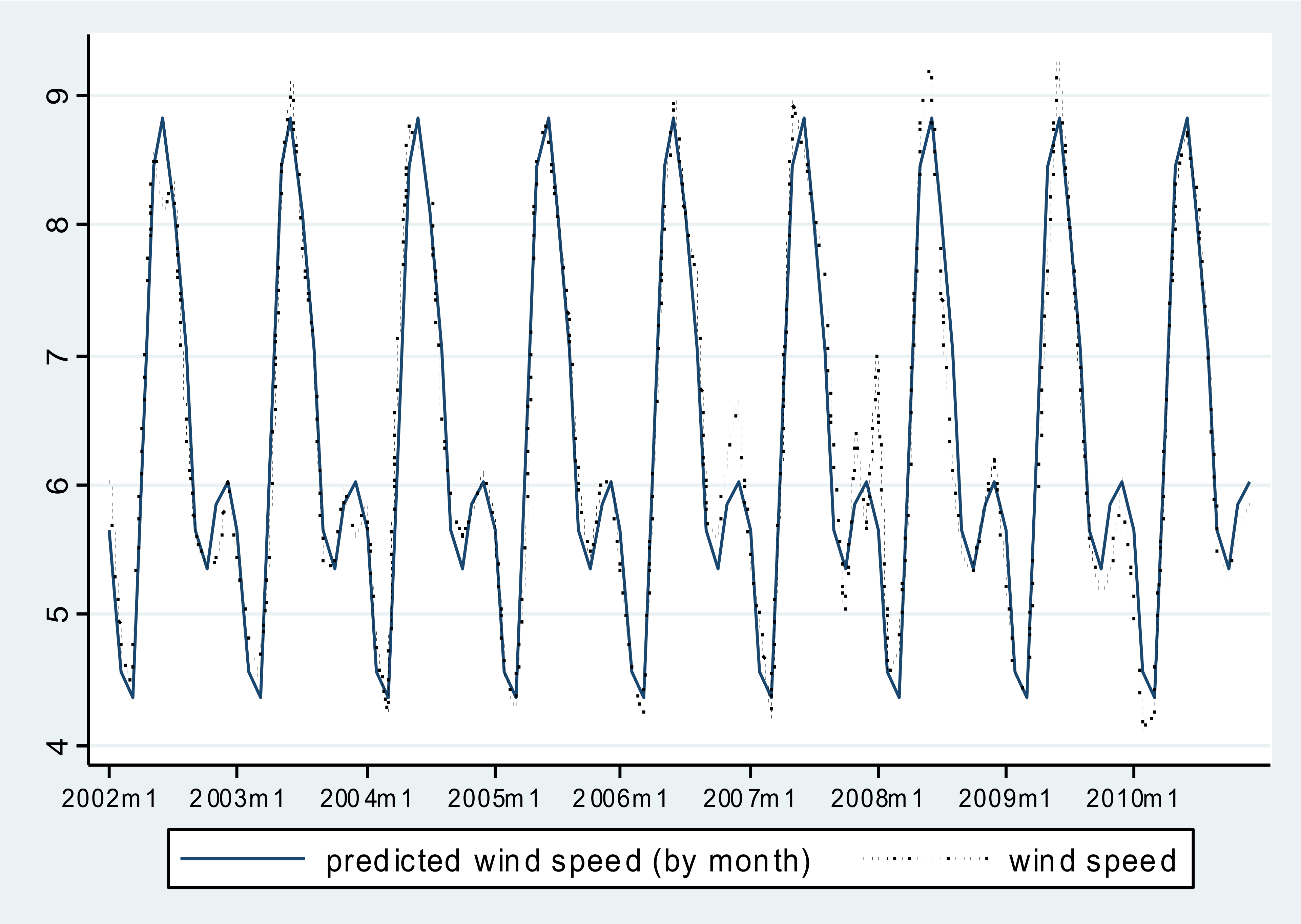


Figure A2: Wind Speed and Attacks in the Somalia Area