Online Appendix

This is the online appendix for *The Welfare Cost of Lawlessness: Evidence from Somali Piracy.*

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.[57] 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.[58]. This will give us, in case

[57] 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`.

[58] 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`

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 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 wind speed 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.[59] 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 corresponding to our grid. We use this to compute the average wind speed in any month for both the Somalia 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

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

This regression has an R^2 of 0.997. The strong seasonal pattern is also apparent in figure A1

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

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 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.[60]

[60] The R package is available from `http://www.goo.gl/BCj6G`. The procedure and the code used is available from `http://www.goo.gl/irRxgv`.

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 Alternative Competitive Environments

We measure shipping prices but want to identify the effect of piracy on shipping costs. With the pass through rate ρ_{dt} in dyad d at time t we can write the shipping price

$$p_{dt} = \rho_{dt} \times C\left(s, d, t, A_{dt}\right).$$

Changes in the pass-through rate is what would drive a wedge between log rates and attacks

$$\log p_{dt} = \log \rho_{dt} + \log C\left(s, d, t, A_{dt}\right) = \log \rho_{dt} + c\left(s, d, t\right) + \gamma A_{dt} + \beta x_{dst} + \eta_{dst} \qquad (13)$$

Fabinger and Weyl (2012) show that in a symmetric industry the symmetric price charged by firms can be described by the pass through rate

$$\rho_{dt} = \frac{dp_{dt}}{dC(.)} = \frac{1}{1 - \theta_{dt}\mu'\left(p_{dt}\right)}$$

where $\mu'\left(p_{dt}\right)$ measures the log-curvature of demand and θ_{dt} is constant under fairly general conditions. We are interested in the change in this rate with changes in costs. This is given by

$$\rho'_{dt} = \frac{\theta_{dt}\mu''\left(p_{dt}\right)}{\left(1 - \theta_{dt}\mu'\left(p_{dt}\right)\right)^2}.$$

The assumption of constant pass-through implies $\mu''\left(p_{dt}\right) = 0$. In the constant elasticity world used in the welfare calculations, for example, we have $\mu'\left(p\right) = -\frac{1}{\epsilon}$. This yields $\rho' = 0$ so that ρ_{dt} is not directly related to prices and therefore does not introduce a bias.

Note that even variation in θ_{dt} or ρ_{dt} would not per se constitute a problem for our identification strategy as long as they change across the d or t dimension.

C Predicting Pirate Attacks

This Appendix discusses table A2 which reports the predictive power of five different ways to model equation (1). Our 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. $E\left[a_{t+1}\right] = a_t$. The result is reported in column (1) of Table A2.

As an alternative, we also fitted an AR(2) process to the pattern of attacks in the piracy region which we report in column (2) of Table A2. The R squared of this model is only marginally higher than in the baseline model.

In section 3.4 we also discuss two Markov Chain models which have a more intuitive appeal in the context of the distinct shift in pirate activity after May 2008. The first model uses a Markov Chain to model just the shift from one mean number of attacks to another. We report the fit to the actual attacks in column (3) of Table A2. This model performs slightly worse than the baseline.

The second model distinguishes twelve different means, one for each month, in each regime. As can be seen in column (4) this, season specific, Markov Chain model produces an extremely good fit to the realized number of attacks.

Finally, we gathered data on google searches on "Somali piracy", a proxy for news stories, which we use to predict attacks. Results are presented in column (5) of Table A2. This variable performs worse than any of the models using the attacks data which suggests that news stories lag attacks instead of leading them. Column (6) shows that news do not add additional predictive power beyond attacks. In columns (7) and (8) we run the same analysis for the search term "Gulf of Aden".

D Markov Chain Forecasts

D.1 Basics

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

$$a_t = \mu_\ell \left(1 - \delta\left(\ell_t\right)\right) + \mu_W \delta\left(\ell_t\right) + \varepsilon_t \quad \text{with } \varepsilon_t \sim N(0, \sigma^2_{\ell_t}) \tag{14}$$

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

	$\ell_{t-1} = W$	$\ell_{t-1} = S$
$\ell_t = W$	p	$1 - q$
$\ell_t = S$	$1 - p$	q

at date t, follows the process:

$$\ell_t = 1 - q + \lambda \ell_{t-1} + v_t \text{ where } \lambda = q + p - 1$$

where v_t is an error term with a state-contingent distribution of

$$v_t \mid (\ell_{t-1} = W) = \begin{cases} 1-p & \text{with probability} \quad p \\ -p & \text{with probability} \quad 1-p \end{cases}$$

and

$$v_t \mid (\ell_{t-1} = S) = \begin{cases} -(1-q) & \text{with probability} \quad q \\ q & \text{with probability} \quad 1-q. \end{cases}$$

The model has a vector of six region-specific parameters

$$\theta \equiv \left\{\mu_W, \mu_{S,}\sigma_W^2, \sigma_S^2, p, q\right\}$$

which is a complete description of the parameters governing the process of piracy. Most of our use of the model will turn around just four parameters from this vector: μ_W, μ_S, p and q

The history of attacks is used to estimate the probability $P(\ell_t = W \mid H_t, \theta)$ given the attack history H_t and the parameter vector θ. (Details are provided below.) This probability can then be used to form expectations about the level of future attacks, i.e. a_{t+1}. It is easy to show that given equation (14) the estimate of attacks in the next month is

$$\begin{aligned} E(a_{t+1} : H_t) &= \mu_W(1-q) + \mu_S q \\ &\quad + (\mu_W - \mu_S)\lambda P(s_t = W \mid H_t, \theta) \end{aligned} \tag{15}$$

where $\lambda \equiv p + q - 1$. The first two terms in equation (15) are time-invariant functions of the regional parameters θ. One can interpret them as the expected level of attacks in times of inactivity, i.e. at $P(s_t = W \mid H_t, \theta) = 0$. 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.

D.2 Estimation

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

$$P(\ell_t = W \mid H_t, \theta) = \frac{f(a_t \mid \ell_t = W, H_{t-1}, \theta)\, P(\ell_t = W \mid H_{t-1}, \theta)}{\sum_{j=S}^{W} f(a_t \mid \ell_t = j, H_{t-1}, \theta)\, P(\ell_t = W \mid H_{t-1}, \theta)}.$$

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

$$f\left(a_t \mid \ell_t = j, H_{t-1}, \theta\right) = \frac{1}{\sqrt{2\pi\sigma_j^2}} \exp\left(-\frac{\left(a_t - \mu_j\right)^2}{2\sigma_j^2}\right)$$

and therefore depend on parameters in θ.

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

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

and

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

where $P\left(\ell_t = W \mid \ell_{t-1} = j\right)$ is nothing else than the estimated p and $1 - q$ contained in θ. Hence, one needs $P\left(\ell_{t-1} = W \mid H_{t-1}, \theta\right)$ to calculate $P\left(\ell_t = W \mid H_t, \theta\right)$.

This reliance of $P\left(\ell_t = W \mid H_t, \theta\right)$ on $P\left(\ell_{t-1} = W \mid H_{t-1}, \theta\right)$ implies that previous probabilities of conflict have to be calculated first. The filter therefore takes a starting value $P\left(\ell_0 = 1 \mid H_0, \theta\right)$ and calculates

$$P\left(\ell_1 = 1 \mid H_1, \theta\right), P\left(\ell_2 = 1 \mid H_2, \theta\right) ... P\left(\ell_T = 1 \mid H_T, \theta\right)$$

by iteratively updating the probability of conflict with the monthly attacks data a_t. To some degree this is what the charter parties of a shipment through the Somalia area would have done, too.

However, this simple filter relies on the availability of the vector θ. The problem is that θ cannot be calculated without knowing the states $\ell_1, \ell_2 ... \ell_T$ 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 by iteration.

In each iteration the algorithm makes use of the "smoothed" probability of conflict which is based on the entire attack time series data

$$P\left(\ell_t = 1 \mid a_T, a_{T-1}, ..., a_1, \theta\right).$$

Nothing in the process changes if we assume a distinct value of μ_{jm} that is a function of the month in addition to the state. The EM algorithm simply fits 12 means instead of 1 mean per state and calculates probabilities $P(\ell_t = 1 \mid a_T, a_{T-1}, ..., a_1, \theta_m)$ as described above.

E Cost Factors

E.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.[61] 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 large rectangle in Figure 2.[62] Cargo insurances do not typically charge additional premiums for specific sea areas.[63] Since hull damage is covered by insurance we expect such costs to be passed on to ship charterers.

E.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.[64] With an estimated rolling average of 205 days under seizure at the end of 2010 this implies a relatively even share of costs.[65] 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

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

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

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

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

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

without maintenance is bound to incapacitate a ship.

E.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.[66] 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.[67] 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.[68] 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.

E.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.[69] 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.[70] Conversations with industry experts suggest that the price per security crew of four is fixed and does not generally vary with 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.

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

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

[68] 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`.

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

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

E.5 Re-routing, Speeding-up

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.[71] 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.[72] Rerouting costs are in principle fully recoverable from the charterer since contracts are written for daily ship hire. A different issue are additional fuel costs which are borne by the charterer under the time-charter.

E.6 Additional Wage Costs

There are large welfare costs borne by the captured individuals in hijacking incidents. With captivity lasting on average 11 months and a high level of physical violence the hijacking risk looms large for individuals. In addition, according to the Ocean's Beyond Piracy think tank 3,863 seafarers were fired upon by pirates in 2012. It is difficult to measure this human cost in monetary terms. Still, one way to capture it is the wage compensation that seafarers receive when shipping through piracy areas. After negotiations in the International Bargaining Forum (IBF) it was agreed that workers should be entitled to a 100 percent basic wage bonus to compensate for travels through war risk areas. As this cost is directly borne by the shipowner it will also increase shipping rates in a competitive market.

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.

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

[72] See One Earth Future (2011).

F Welfare Cost Calculations

F.1 Basic Estimate

The first column in Table 7 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).

Total Cargo shipped through the Suez Canal is around 646,064,000 tons per year.[73] 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 7 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 same estimates as before and estimate the number of 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).[74] 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:

$$\begin{aligned} 0.082 * 0.4726 * 30.3 * 646064000 &= 758 \text{ million USD} \\ &\quad -120 \text{ million USD} \\ &= 638 \text{ million USD} \end{aligned}$$

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

[74]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.

Gulf of Aden+Indian Ocean:

$$\begin{aligned} 0.082 * 0.4726 * 30.3 * 646064000 &= 758 \text{ million USD} \\ 0.082 * 0.4648 * 20.67 * 578000000 &= 455 \text{ million USD} \\ & \quad -120 \text{ million USD} \\ &= 1,093 \text{ billion USD.} \end{aligned}$$

High estimate:

Our high estimate uses the estimate on the dummy on war area risk from Column (4) Table 5 to derive the costs of piracy. That estimate suggests that piracy leads to an increase of charter rates by 12.3%.

Gulf of Aden:

$$\begin{aligned} 0.123 * 0.4726 * 30.3 * 646064000 &= 1,137 \text{ million USD} \\ & \quad -120 \text{ million USD} \\ &= 1017 \text{ million USD} \end{aligned}$$

Gulf of Aden+Indian Ocean: we use the same coefficient but apply it to the Indian Ocean Trade Thus:

$$\begin{aligned} 0.123 * 0.4726 * 30.3 * 646064000 &= 1,137 \text{ million USD} \\ 0.123 * 0.4648 * 20.67 * 578000000 &= 683 \text{ million USD} \\ & \quad -120 \text{ million USD} \\ &= 1,700 \text{ billion USD.} \end{aligned}$$

Column (2) in Table 7 applies the additional factor derived in equation (11). Details are in the following section.

F.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

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

When we derive the partial derivative using

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

we find that

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

Now observe that:

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

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

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

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

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

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

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

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 (10) 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

$$\frac{\Delta}{c+\Delta} = 0.082$$

while in the high estimate it is

$$\frac{\Delta}{c+\Delta} = 0.123.$$

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

$$\begin{aligned} L^2(\Delta) &= L^1(\Delta) \times \left[1 + \frac{1}{2}\left(1 - \frac{\tau(\Delta)}{\Delta}\right)\frac{\Delta}{c+\Delta}\hat{\eta}\right] \\ &= L^1(\Delta) \times 1.017 \end{aligned}$$

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

$$(758 \text{ million USD} - 120 \text{ million USD}) \times 1.017 = 649 \text{ million USD}.$$

F.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 7).

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[75], 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:

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

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

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.[76] 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

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.

[76] 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 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 7 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 column (3), Table 7.

G Cost of Military Operations

While somewhat sketchy, our estimates in Table 7 can be augmented to include the costs of naval operations which try to limit pirate activities. The costs of Atalanta for the European Union in 2009 was 11 million USD.[77] 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.[78] 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.

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

[78] 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.*

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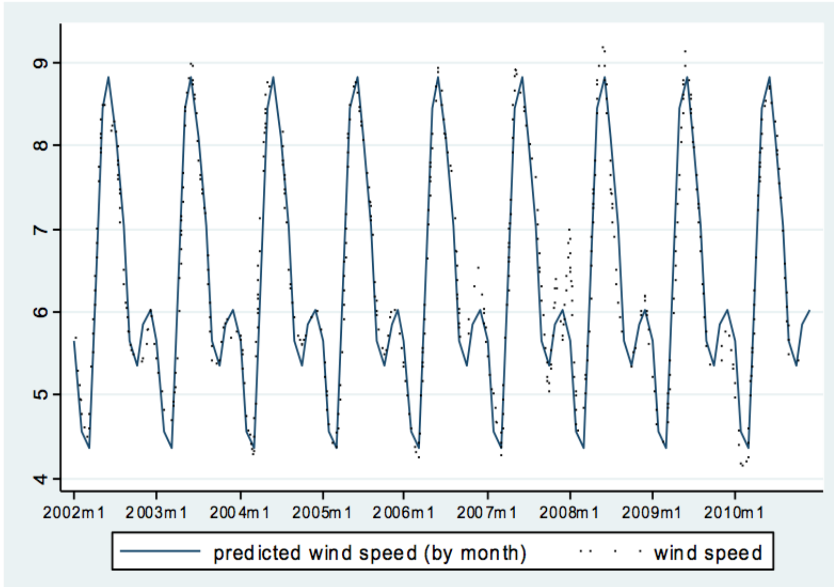

Figure A1: Wind Speed in the Somalia Area

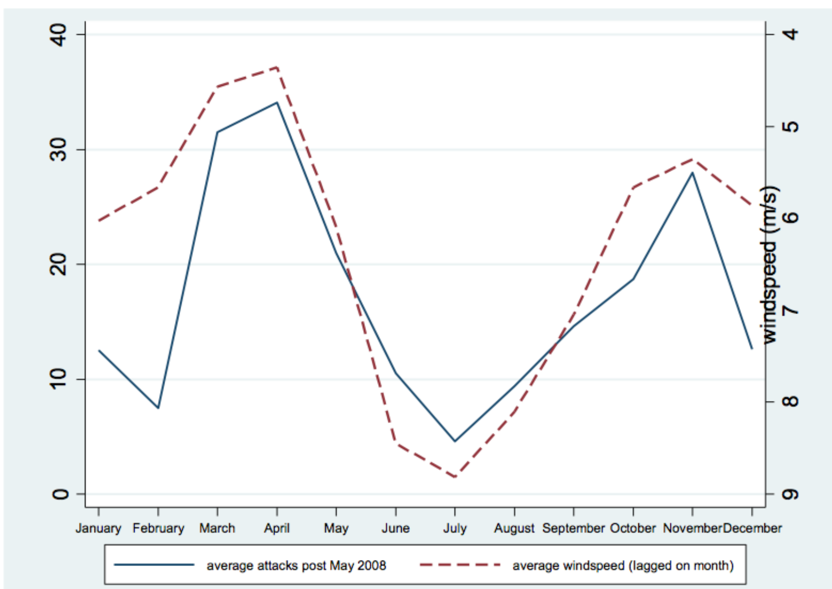

Figure A2: Wind Speed and Attacks in the Somalia Area

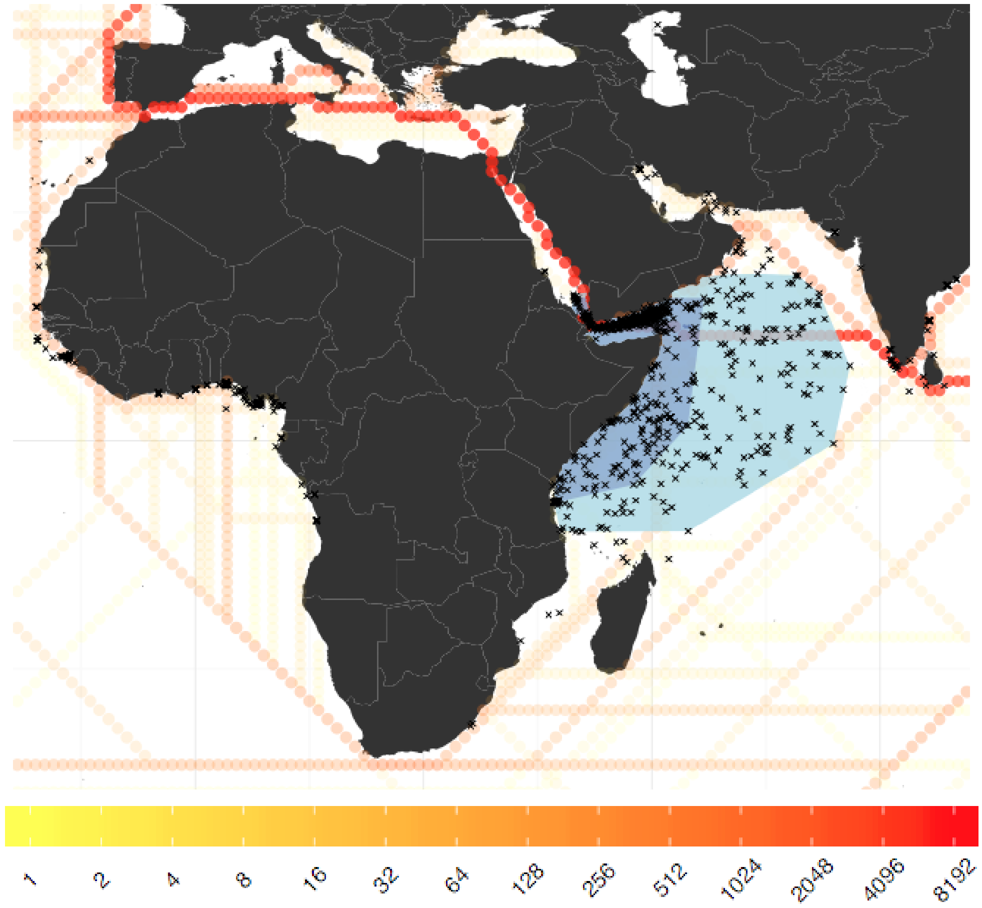

Figure A3: Calculated Shipping Lanes and Treatment Areas Based on Convex Hulls
Note: The dark shaded area on the interior is the convex hull spanned by all attacks up to 2005, while the bigger light shaded area is the convex hull spanned by all attacks up to 2010. The location of attacks is indicated by a cross. The circles indicate the shipping lanes, the colouring of which is proportional to the number of observation on each shipping lane according to the continuous colour scheme.

Table A1: Summary Statistics of Main Variables

Variable	Mean	Std. Dev.	Min	Max
trade value (in Mio USD)	3831.42	8101.499	0	42034.211
log(trade value+1)	18.767	5.739	0	24.462
shipage (in years)	9.45	7.31	0	39
deadweight tonnage (dwt)	80092.19	39495.48	5169	300000
rate per day per dwt (in USD)	0.45	0.30	0.01	4.04
ballast bonus per dwt (in USD)	1.03	70.26	0	1.10E+04
distance (in km)	8014	6846	0	2.41E+04
number of attacks in Somalia	7.03	9.06	0	42
number of attacks in Gulf of Aden	4.116	5.493	0	22
average predicted wind speed in m/s (Somalia)	6.34	1.38	4.36	8.81
forecast number of attacks Somalia (Markov Chain)	7.73	5.22	2.79	14.20
forecast number of attacks Somalia (AR(2))	14.59	13.75	1.98	57.26

Table A2: Predictive Power of Expectation Models

	Different Expectation Models				Google Searches			
	(1) Lagged Attacks	(2) AR(2)	(3) EM	(4) EM (seasonal)	(5) Somali Piracy	(6) Somali Piracy	(7) Gulf of Aden	(8) Gulf of Aden
forecasted attacks	0.717***	0.710***	0.719***	0.909***		0.621***		0.652***
	(0.099)	(0.097)	(0.107)	(0.072)		(0.166)		(0.148)
Searches "Somali Piracy"					0.166***	0.032		
					(0.032)	(0.043)		
Searches "Gulf of Aden"							0.046**	0.008
							(0.018)	(0.015)
Observations	98	98	98	98	83	83	83	83
R-squared	.51	.511	.426	.807	.303	.489	.202	.488

Notes: Results from a regression of piracy in a month on various models of expectations. Robust standard errors reported in parentheses, with stars indicating *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Note that the Google Search data is only available from 2004 onwards.