Timothy Besley, Thiemo Fetzer and Hannes Mueller

The welfare cost of lawlessness: evidence from Somali piracy

Article (Accepted version) (Refereed)

Original citation:
Besley, Timothy, Fetzer, Thiemo and Mueller, Hannes (2015) *The welfare cost of lawlessness: evidence from Somali piracy.* Journal of the European Economic Association, 13 (2). pp. 203-239. ISSN 1542-4766

DOI: 10.1111/jeea.12114

The Welfare Cost of Lawlessness: Evidence from Somali Piracy*

Timothy Besley†
LSE and CIFAR

Thiemo Fetzer‡
LSE and STICERD

Hannes Mueller§
IAE (CSIC) and Barcelona GSE

May 27, 2014

Abstract

In spite of general agreement that establishing the rule of law is central to properly functioning economies, little is known about the cost of law and order breakdowns. This paper studies a specific context of this by estimating the effect of Somali piracy attacks on shipping costs using data on shipping contracts in the dry bulk market. To

*We are grateful to the editor, referees, Daron Acemoglu, Elhanan Helpman, Marit Rehavi and a number of seminar participants for useful comments and advice. We also thank Dieter Berg, Tilman Kratz, Richard Mcenery, Richard Neylon, and Neil Roberts for their many helpful insights into the workings of the industry. Ali Saadatnia and Alessandro Torti provided valuable research assistance. We thank the International Growth Centre (IGC) at LSE for financial assistance in collecting the data. For additional support, Besley thanks CIFAR and Martin Newson, Fetzer thanks the Konrad Adenauer Foundation and Mueller thanks Spanish Ministry of Economy and Competitiveness through the Severo Ochoa Programme for Centers of Excellence in R&D (SEV-2011-0075), from project number ECO2012-37857 and the Ramon y Cajal programme. Responsibilty for errors lies with the authors.

†Department of Economics, London School of Economics, Houghton Street, London WC2A 2AE, United Kingdom. Email: t.besley@lse.ac.uk.

‡STICERD, London School of Economics, Houghton Street, London WC2A 2AE, United Kingdom. Contact: `www.trfetzer.com`.

§Institut d'Analisi Economica, CSIC Campus UAB, 08193 Bellaterra (Barcelona), Spain. Email: hannes.mueller@iae.csic.es.

estimate the effect of piracy, we look at shipping routes whose shortest path exposes them to piracy and find that the increase in attacks in 2008 lead to around a 8 to 12 percent increase in costs. From this we calculate the welfare loss imposed by piracy. We estimate that generating around 120 USD million of revenue for Somali pirates led to a welfare loss in excess of 630 USD million, making piracy an expensive way of making transfers.

1 Introduction

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

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.

In this paper, we match data on piracy attacks in the maritime area around Somalia to data on around 24,000 shipping contracts 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 the main areas affected by Somali piracy to estimate the impact of piracy on shipping costs. We use these estimates to calibrate a model of the welfare cost of Somali piracy.

Figure 1 previews our findings by showing the relationship between piracy attacks in Somalia and a non-parametric estimate of the additional shipping cost paid on routes through the piracy area.[3] There is a visible association between the two variables. Both shift upwards in mid 2008 after the maritime area is declared a piracy risk area by the maritime insurance industry in May 2008.

Our regression results show that shipping costs for dry bulk goods rose by between 8 and

[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 the One Earth Future Foundation (2010, 2011) reports. Our direct approach is distinct from these reports. A recent World Bank (2013) report calculates the welfare effects with a gravity trade model but finds mostly insignificant effects of piracy on trade.

[3]We constructed Figure 1 by regressing shipping costs on route and time fixed effects and a set of time dummies for those trade routes going through the Somalia area. The coefficients on these dummies allow us to draw charter rate differentials across time. Figure 1 shows the rolling average of the estimated coefficients of this regression together with the rolling average of attacks.

12 percent when pirate activity increased in Somalia. We also show that these larger shifts mask significant variation across months. Charter rates fluctuate by 18 percent between the most and least dangerous months. This seasonal pattern in shipping prices is absent prior to the upsurge in pirate activity in the region during 2008. Accounting for this seasonal variation highlights that the average shipping costs through the Somali area did not increase during the months in which weather conditions inhibit pirates from operating.

The extra shipping costs that we uncover are mostly due to higher insurance costs and the increased security measures that are needed to repel pirate attacks. These constitute a welfare cost to the extent that labor and resources are allocated from productive tasks towards protection. Our model compares 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 (somewhat conservative) 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.

Studying Somali piracy provides a unique opportunity to measure the costs of economic predation. Moreover, the factors that lie behind the welfare costs in this context are generic. In particular, it is useful to reflect on why taxation is less costly than predation. Ideally, a state that levies taxes has the capacity to ensure compliance and to commit to providing security to those who pay those taxes. Economic predators typically lack both of these capacities. Somali pirates can extract resources only by attacking ships while ship owners only have the option to invest in defence or bear the cost of predation. We show empirically that, in this situation, large costs can be occurred even when the amount extracted from predation is fairly small.[4]

This article belongs to a wider literature on the value of establishing the rule of law and its role in securing trade and investment.[5] A traditional problem in weakly-institutionalized

[4]Our arguments are akin to the distinction between roving and stationary bandits in Olsen (1993). Bandiera (2003) argues that fractionalized ownership reinforces this problem in the context of the Sicilian Mafia.

[5]See Dixit (2004) and Rose-Ackerman (2010) for literature overviews. Mauro (1995) and Aidt (2003)

environments is that bringing goods to market is subject to predation and theft.[6] The consequences of the failure to establish and enforce property rights is a core theme in the development literature such as Keefer and Knack (1995) and Acemoglu, Johnson and Robinson (2001). Piracy is a specific consequence of state failure because it creates a spill-over of insecurity from one country to a maritime region. We show that in the case of Somalia this has taken on striking dimensions with shipping through the whole of the Indian Ocean now affected. We argue that the consequent predation generates sizeable costs relative to the revenues that it raises for pirates.

A recent literature has studied the economic effects of an extreme case of state failure, namely violent conflict.[7] Guidolin and LaFerrara (2007) provide the example of diamond mining companies benefiting from local conflict. Besley and Mueller (2012) provide a framework to capture the effect of expected violence on housing prices which we use for our estimation. Voors et al (2012) show that violence in Burundi affected individual preferences permanently. In particular, they find that individuals that were exposed to violence became more risk seeking. Disruptive, high risk activities, like piracy, are therefore more likely to arise in a conflict setting.

Piracy poses a particular issue because of the difficulty of securing international agreement over the assignment of responsibility to deal with the problem and how the costs of such efforts are to be 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. Our calculation of the welfare cost gives a sense of the magnitude of the potential benefit to greater security.

Insecurity due to piracy leads to 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

review the literature on corruption and growth.

[6] Anderson and Marcouiller (2004) and Anderson and Bandiera (2006) study the link between predation and trade. Olken and Barron (2009) study predation in the context of trucking in Indonesia.

[7] See Blattman and Miguel (2009) for an review of the literature on civil war. See Bermann et al. (2012) for a recent study on the Philippines.

costs for trade patterns. In particular, it is related to Mirza and Verdier (2008) which studies how international terrorism affects trade costs.[8] Our model allows us to calculate the likely impact of the estimated increase in shipping costs on trade. For this purpose, we use recent findings by Feyrer (2009) who studies the Suez Canal closure 1967-1975. It has been argued in the context of Somali piracy that it has reduced shipping and led to a re-routing of ships.[9] We show both empirically and theoretically that the effects on trade volumes due to piracy are likely to have been small.

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. Section 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 can be matched to specific shipping routes.

2.1 Piracy Data

Our data on piracy 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).[10]

[8] For reviews of the extent of trade costs and their importance in explaining patterns of trade see Anderson and van Wincoop (2004), Behar and Venables (2011) and Hummels (2007). Donaldson (2010) is a recent study of the impact of a change in trade costs due to the construction of railroads in India.

[9] One Earth Future Foundation (2010) calculates large costs from re-routing around the cape of Good Hope. This cost is dropped in the One Earth Future Foundation (2011) report which argues that re-routing around the cape was unlikely to be an issue.

[10] We discuss our data in more detail in appendix A. Table A1 provides summary statistics.

We geo-code attacks and focus on the Somali area which we define as the rectangle spanned by the coordinates S11, E38.4 and N18.3, E74.7 depicted as the shaded area in Figure 2. We focus on this area because we believe that there are common factors driving piracy attacks within this zone, i.e. if pirates attack in some point along the Somali coast, it is informative about the likelihood of an attack elsewhere within the area. The crosses in Figure 2 represent the locations of the piracy attacks. Figure 2 also depicts a geographically narrower area in a darker shade, the Gulf of Aden, which we use as a robustness check on our main results below. Piracy in the Somalia area is a sophisticated crime with a large number of ships being hijacked. Pirates rely on external finance, political support and safe havens on the Somali coast to operate effectively.[11]

Figure 3 illustrates the time-series variation in piracy attacks, showing the upsurge in attacks during 2008. We exploit this to study the effect of Somali piracy on shipping costs. Interpreting this as an effect of piracy requires us to be sure that there was no change in amounts shipped due to piracy during 2008. We show in section 3.5 that, if anything, shipping through Somalia decreased during 2008 making it highly unlikely that changes in traffic patterns were responsible for the increase in pirate activity. There is a consensus among experts on Somali piracy that the origins of the increase in pirate activity lie in what happened on land rather than at sea. Hansen (2009), for example, argues that a key trigger for the increase in piracy attacks was the crisis in public finances in the Puntland government in Somalia which left it unable to pay the police. This, he argues, along with the generally weak state of law and order in Somalia, made it increasingly feasible for pirates to operate without sanction. Pirates had long masqueraded as coast guards protecting Somali territorial waters from illegal fishing. This cloaked a build up of organized violence which emerged strongly after May 2008.

The developments were closely observed by the maritime insurance industry. Table 1

[11] A previous draft of this paper studied piracy in the broader Indonesia area. However, the type of piracy which takes place there is distinct from Somali piracy. It consists mainly of armed robbery, which takes place in ports. Hence, arguably its consequences are less severe and are easier to control.

summarizes the piracy 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.

Aside from the structural break, seasonality induced by wind conditions plays a crucial role in the pattern of piracy, something which we will exploit in our empirical analysis. Most of the attacks are carried out using small vessels, known as "skiffs". These are typically between 7 and 10 metres 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 the level piracy attacks is rather similar to pre May 2008 levels. The calm spring period is the most dangerous time with over 30 attacks in March and April. The close link between this seasonal pattern in attacks and wind speeds is discussed in more detail 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.[12] 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

[12] 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`. There are many shipping consultants, however, Cotzias consistently made data available for a long time period. The selection of a particular shipping consultant will only affect our results in case there is a time varying bias to reporting charter contracts on Somalia routes that is correlated with the onset or intensity of piracy. We do not believe this is the case.

charterers take an active interest in reports of recent transactions.[13] 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 for fuel (known as *bunkers*) 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 lengths.

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.

2.3 Piracy Risks and Shipping Costs

There have been a number of 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.[14]

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

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

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, speeding-up of vessels to avoid areas at risk (vi) extra wages paid to the crew compensate for the risk of being kidnapped. We discuss these cost factors in detail in Appendix E. 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.[15]

We use shipping contracts to measure the cost of shipping. These reflect the consequences of piracy to the extent that costs of piracy are borne by the ship owner and passed on 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:[16]

> "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, charterers have to compensate ship owners for extra costs created by piracy risk on the chartered route. However, it is still possible that some of the pirate costs are borne directly by the charterer which would result in us underestimating the cost of piracy. In section (3.5) we therefore discuss the sensitivity of our welfare estimates to the exact division of piracy costs between ship owners and charterers. Specifically, we calculate the welfare cost under the assumption that piracy costs are shared according to the General Average (GA) rule which is widely used in the shipping industry and is explained below.

[15] There are debates about whether this assumption is reasonable. If it were not the case then markups in this industry would create a further potential welfare cost from piracy.

[16] 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 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 the Somalia area. However, there are some cases where it is not entirely clear whether the vessel would travel on a Pacific route or through the Indian Ocean and Atlantic using the Suez canal. In assigning piracy risk to a specific route, we employ a path algorithm to obtain an automatic coding of that route.[17] We are then able to see whether the shortest sea route passes though the piracy areas that we study. If it does, we suppose that the shipping contract is subject to a piracy risk based on the forecast number of attacks in the relevant region at a point in time.

Figure 2 provides a bird's-eye view of the trade-routes for the areas around Somalia based on our path algorithm. The points which are less opaque and more deeply shaded in red represent more ships going through a particular route. We suppose that a shipping route is more vulnerable to piracy attack if it crosses the rectangles in Figure 2. As a check on our core results, we construct a measure of a route being vulnerable to piracy attack based on it passing through the convex hull which is spanned by all such attacks up to each year. This measure is arguably more satisfactory since it takes into account the fact that the Somali pirates were able to expand their reach into the Indian Ocean since 2008. The empirical findings are similar when either method of assigning vulnerability to piracy attacks is used.

It is possible that some ships re-routed around the Cape of Good Hope to avoid exposure to piracy risks. We check for this possibility below and find no evidence for changes in either the extent of traffic through the Suez Canal or in the composition of ship size through affected areas after the upsurge in piracy attacks. Moreover, assigning piracy risk to routes allowing the possibility of re-routing when this would add relatively little distance to the journey, makes our results even stronger. This supports the view of other commentators,

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

such as One Earth Future (2011), that re-routing around the Cape in response to piracy is not important.

We do not distinguish between attacks on different types of vessel (container, tanker, dry bulk, etc.) since all varieties of ship, including all sizes, have been attacked and hijacked in the piracy-affected area. The first successful hijack of a dry bulk ship took place as early as May 2008.[18] Attacks seem sufficiently random across of a range of ship types and so we do not to attempt to distinguish empirically between different sizes of bulk ships.

2.5 A Model of Piracy Attacks

To motivate the time-series variation in piracy attacks, consider the following simple theoretical model. Suppose that there are M active pirate ships and that in each period each pirate receives an opportunity to hijack a ship where V_{it} is the benefit and c_{it} is the cost.[19] Pirate i at date t will launch an attack if the expected benefit exceeds the cost:

$$\xi_t V_{it} \geq c_{it}$$

where ξ_t is the success probability, V_{it} is the value of a successful attack and c_{it} is the cost.

A key parameter is the cost-benefit ratio $\rho_{it} = c_{it}/V_{it}$. We suppose that ρ_{it} is drawn for each pirate ship i at date t from a uniform distribution with mean θ_t. Given M independent

[18] According to a Lloyds List report on July 2008 the ship was freed 41 days later for a ransom of 0.75 million USD.

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

$$E\left\{V_{it} - c_{it} : \xi_t\right\} > F_i$$

in which case we would also predict that M would be a function of ξ_t, i.e.

$$M_t = H\left(\xi_t\right).$$

So we would have

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

and the expected number of pirate attacks will still depend on ξ_t reflecting underlying law and order.

draws the expected number of pirate attacks at date t is given by:

$$E[a_t] = \xi_t M. \tag{1}$$

The variation in expected piracy attacks in equation (1) is then captured by ξ_t which we assume reflects two things. First, there can be short-term factors which shape piracy costs and benefits, including weather variation. 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 lead to a permanent shift in the feasibility to conduct piracy. To capture these two factors we allow the success probability, ξ_t, to be related empirically to climatic conditions and the insurance evaluation of the industry which requires ships to insure against war risks since May 2008.

3 The Effect of Piracy on Shipping Costs

In this section, we present estimates of the effect of piracy attacks on shipping costs. We will begin with a comparison of mean shipping costs between regions affected by Somali piracy before and after the upsurge in attacks in 2008. We then present regression-based estimates.

3.1 Difference in Difference Estimates

We present a simple difference-in-difference estimate of the effect of Somali piracy on mean shipping costs by looking at the routes affected by piracy before and after May 2008 compared to all other routes. The result of this exercise is reported in Table 2 which gives the average rate per DWT on routes which pass through the Somalia area compared to other shipping routes before and after May 2008.

Column (1) shows that the average shipping costs were not significantly different between routes before May 2008. However, they diverge after that date with the mean cost per DWT being significantly above the rate for other routes by 0.074 USD per day per DWT. This represents an increase of around 15%. This result parallels the finding in Figure 1 which also compared affected routes before and after piracy began. The key identifying assumption is that the influence of other time-varying factors which are affecting shipping costs have a common impact on both sets of routes. In particular, the global recession which led to a fall in trade and shipping rates in winter 2008 is assumed to influence routes that are affected by piracy and those that are not to the same degree.[20]

We now turn to investigating how this finding holds up in regression evidence based on individual shipping contracts.

3.2 Piracy Attacks and Shipping Costs

Our core regression specification assumes that the dry bulk shipping market is contestable so that pricing is based on the average cost per day for each voyage.[21] 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.[22] 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.

[20] We run a number of robustness checks with regard to changes in the economic environment in section 3.4.

[21] Shipping has the classic conditions for a perfectly contestable market: (i) no entry or exit barriers (ii) no sunk costs and (iii) access to the same level of technology (to incumbent firms and new entrants). This is essentially the model of the Bulk shipping market used in Kalouptsidi (2014) who also assumes competitive freight rates. See Behar and Venables (2011) for a discussion of the extent of contestability in shipping markets. In Appendix (B) we show that with constant pass-through we can identify the effect of piracy attacks on shipping costs from changes in rates, even if shipping markets are not perfectly competitive.

[22] 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.

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 a treatment indicator for each route depending on whether it passes through the area of Somalia. Denote this as a dummy variable where $\delta_d = 1$ if route d passes through piracy. Then:

$$A_{dt}=\delta_d\times a_t.$$

is our measure of the cost shock expected on route d where, in the core specification, a_t is the recorded level of pirate attacks in the Somali piracy area in month t. In the basic specification, we do not the effect of piracy attacks to vary with ship size, s, or route, d. However, we will 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. $E\left[a_{t+1}\right]=a_t$. 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.[23]

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

[23] We discuss the prediction of pirate attacks in detail in appendix C.

and month. The standard errors ε_{isdt} are adjusted for two-way clustering on origin- and destination country. Other controls in x_{dt} include the age of the ship and the ballast bonus per DWT (a bonus paid for empty return journeys).

Our key identifying assumption is that factors that drive piracy, the factors in ξ_t in equation (1) are orthogonal to other drivers of shipping costs, conditional on the controls that we use. Month fixed effects, α_t, for example, should capture changes in the operating costs which affect all routes. The fact that bulk shipping is a competitive world market makes the inclusion of these dummies particularly important.

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 a region 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 3 which uses the specification in (3). We normalize the piracy attacks variable in columns (1) to (2) such that the coefficients can be interpreted as the percentage point increase in shipping costs with the shift in pirate activity around May 2008.

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 shipping costs were around 8.2 percent higher after the upsurge in piracy.

The ship size dummy variables show evidence of significant scale economies in shipping with the smallest ships being around 62 percent 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 estimate on piracy attacks does not change much after adding these controls.

As we discussed in section 2.1 piracy attacks after May 2008 were highly seasonal. We now ask whether this seasonal variation in attacks affects shipping costs. There are good reasons to believe that seasonal variation in risk is relevant for charter rates. Supplementary insurance to pass through high risk areas, for example, is priced based on specific weeks in high risk zones.[24] Other cost factors such as security crews and ship modifications are adjustable as well.

One way to exploit the seasonality in attacks is presented in column (3). Here we identify the effect of piracy attacks only with data after May 2008. The coefficient on piracy is still positive and significant but somewhat smaller in size. Thus, our findings in column (1) and (2) are not entirely driven by changes on routes through Somalia before and after 2008 but also by month-to-month variation within the years with pirate activity.

Declaring an area as a special war risk area is a significant event in the insurance industry and reflects risk perceptions at the time. 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, added the Gulf of Aden in May 2008. We use a dummy variable to represent this event in equation (3) instead of the level of piracy attacks.[25] This specification is bound to capture the sharp increase in costs depicted in Figure 1. The result is in column (4) of Table 3. The coefficient on the war risk dummy suggests a 12.3 percent increase in shipping costs around May 2008.

[24]The absence of seasonal variation in charter rate differentials would provide opportunities for arbitrage in the insurance market.

[25]May 2008 is in the confidence interval based on our structural break analysis (presented below) but does not coincide with the break date that we found which is July 2008. The results are similar if we use a dummy variable that is equal to one at this slightly later date.

A striking feature of the pattern of attacks is how closely they match with wind speed in the area. In order to exploit exogenous variation in wind speed we create an interaction term between the treatment dummy of column (4) with the monthly average wind speed in the Somalia area. We code the wind speed variable such that it goes from a value of 0 at the maximum wind speed in June to a value of 1 with minimum wind speed in March. In this way the coefficient can be interpreted as the difference in shipping costs between months with maximum and minimum wind speed. The resulting coefficient in the third row of column (5) suggests that charters through Somalia after May 2008 were about 18 percent more costly in March than in June.[26] Moreover, the coefficient on the war risk dummy itself is insignificant suggesting that it was not significantly more costly to charter ships through Somalia sea area in June than it was before the rise in piracy in 2008.

The interaction between the wind speed variable and the indicator that a route is susceptible to Somali piracy is negative. Thus, if anything, there has been the opposite seasonal pattern in charter rates on Somalia routes in the absence of piracy. The fact that pirate activity introduced a seasonal pattern that did not appear previously adds further credibility to the claim that piracy influenced shipping costs.

Figure 4 plots the fitted values from column (5) Table 3. It shows the shipping cost predicted by the Somalia war risk, wind speed and their interaction. The graph illustrates the sharp increase in seasonality in costs after May 2008; shipping costs are roughly twice as high when wind conditions favor piracy attacks after this date.

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 with an average increase in shipping costs of between 8 and 12 percent in the period after piracy attacks increase off the coast of Somalia.

[26] There is a lag between windspeed and piracy attacks of one month. This implies that windspeed at the time of the charter is a good predictor of piracy attacks on the charter route. See Appendix A.3 for details.

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 economic conditions. We also explore alternative definitions of exposure to piracy risk.

A Markov Chain Model for Piracy Attacks 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. $E[a_{t+1}] = a_t$. As a more structural approach, we model the level of piracy attacks using a Markov switching model based on an underlying (latent) 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 in section 3.5. In addition, the Markov Chain model allows for an intuitive way to integrate the discussed seasonality in attacks to make predictions of piracy. This will be discussed in the next sub-section.

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 the model of piracy above, the mean number of pirate attacks in state ℓ is

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

where $\mu_S < \mu_W$.

Dynamics across law and order states are modelled 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 Appendix D.2 that this model gives the following formula corresponding to equation (1) for the expected number of attacks at $t+1$:

$$E\left[a_{t+1}\right]=\Omega+\left(\mu_W-\mu_S\right)\lambda P_t\left(\ell=W\right) \tag{4}$$

where Ω is a constant, λ is a measure of persistence of the process and $P_t\left(\ell=W\right)$ is the probability that the region is in the weak state at time t. The latter is the only time-varying factor in equation (4) and evolves according to the history of piracy attacks. By estimating the parameters of the underlying process, we can construct an empirical counterpart to equation (1).[27]

This type of model, first proposed in Hamilton (1989), has been popular among time series economists modelling 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 $P_t\left(\ell=W\right)$ between values that are close to zero and one while the impact of the estimated probability on expectations is driven by our estimate of $\left(\hat{\mu}_W-\hat{\mu}_S\right)\hat{\lambda}$. 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.

The results when (4) is used instead of a_t to estimate (3) is in column (1) of Table 4. The coefficient on Somali piracy remains significant. Moreover, the estimated increase in piracy costs around May 2008 is similar with 9.2 percent which is only slightly higher than the estimate in column (2) of Table 3.

Column (3) of Table 4 entertains an alternative measure of expectations. We obtain

[27]We discuss details of the estimation in appendix D.2. Note that $P\left(\ell_t=W\right)$, is a function of the particular history of attacks in month t and the set of Markov chain parameters: two state-specific means, two persistence parameters which together determine λ and two state-specific variances. To forecast piracy attacks, we use the observed number of attacks in month t to calculate the probability $P\left(\ell_t=W\right)$ that the region is in a weak state given a set of known parameters. Equation (4) shows that if $P\left(\ell_t=W\right)$ increases then the expected value of attacks next month increases by $\left(\hat{\mu}_W-\hat{\mu}_S\right)\hat{\lambda}$. The estimate for $\left(\hat{\mu}_W-\hat{\mu}_S\right)\hat{\lambda}$ is 11.45 attacks.

data from Google search intensity for the term "Somalia Piracy". This may capture overall expectations about piracy as well. As the coefficient suggests it does predict shipping costs, but as table A2 confirms, it performs a lot worse than any of our other forecast models.

Seasonality The baseline model identifies law and order as the only underlying cause of fluctuations in piracy attacks over time. However, Table 1 also shows a pronounced seasonal pattern which can be incorporated into the empirical model. Suppose that there is a month-specific shock to the success probability, ξ_t. Now the average number of pirate attacks will depend on the month and equation (1) generalizes to

$$\mu_{m\ell} = \xi(\ell) w_m M \tag{5}$$

where w_m is the mean "weather" shock to piracy success in month m. This allows us to rewrite the mean number of attacks as an interaction between an indicator for the weak and strong state, $\ell \in \{S, W\}$, and a monthly mean of attacks during times of weak and strong law and order, α_{mW} and α_{mS}.

$$\mu_{m\ell} = I[\ell = W] \alpha_{mW} + I[\ell = S] \alpha_{mS}.$$

Thus, we have a month-dependent mean in the underlying Markov chain which switches between strong and weak law and order. This model allows us to capture Table 1 perfectly.

The forecast number of attacks at $t+1$ when that month is m is now a function of the probability of the weak state in t and the mean of attacks during weak and strong law and order states for $t+1$. Thus (4) generalizes to:

$$E[a_{mt+1}] = \Omega_m + (\alpha_{mW} - \alpha_{mS}) \lambda P_t(\ell = W) \tag{6}$$

where Ω_m is again a constant (now specific to month m).[28]

[28] We can directly apply the estimation method described in the appendix to a richer parameterization

We show in the Appendix Table A2 that this model outperforms all other models in its predictive power significantly. It allows us to predict 80 percent of the variation in attacks.[29] The coefficient in column (2) in Table 4 confirms previous estimates. We find that the rise in piracy in 2008 led to an increase in shipping costs by 8.7 percent.

Column (3) of Table 4 entertains an alternative measure of expectations that may capture that expectations are a driven by media coverage, instead of past attacks. We obtain data from Google search intensity for the term "Somalia Piracy" for a reduced form measure of news reports. As the coefficient suggests it does predict shipping costs very well.[30]

Omitted Economic Trends By including time dummy variables (for each month), we are controlling for general developments in the global shipping market. These may be important over this period given that the global financial crisis erupts in 2008 alongside a growth in the capacity in bulk shipping. For this to create a problem for our analysis would require that the routes that we have classified as being affected by piracy are differentially influenced by changes in market conditions in a way that increases bulk shipping costs. The main trend in this period is, however, a switch in bulk trade in Asia *away* from Europe and towards other Asian countries, in particular Australia and the Americas.[31] This would tend to work against our core findings as we would expect it to put downward pressure on prices for bulk charter agreements between Europe and Asia which pass through the piracy affected area. Nonetheless, we look at two further ways of controlling for changes in route-specific economic factors.

Column (4) of Table 4 adds GDP growth for the origin and destination of each route to the specification. Due to the coarseness of the destination data in particular (discussed further in Appendix A) we were forced to aggregate to the level of regional GDP for this

with 28 parameters.

[29]We also ran a out of sample forecast in which we predicted pirate attacks in the period 2011 to 2013 with the models in table A2. Again the seasonal EM algorithm outperforms the AR(2) process. Both perform much worse than within sample, however.

[30]We thank an anonymous referee for suggesting this approach. In Appendix table A2, we evaluate the predictive power of news reports over and above passed attacks.

[31]See the detailed discussion in UNCTAD (2011) and UNCTAD (2010).

exercise. Controlling for either annual regional GDP levels (regression not shown), interpolated monthly regional GDP levels (regression not show) or regional GDP growth, as shown in column (5) does not change the main result.

A further possible concern is that trade patterns might change differentially and systematically over time. This concern is particularly important in the light of a recent World Bank (2013) study which tries to identify the effect of piracy from changes in trade. In order to deal with this potential concern, we collected monthly trade data from the IMF Direction of Trade Statistics (DOTS) and matched this to our charter contracts. In column (5) we control for the value of trade on the route of the charter during the same month. Controlling for trade in this way has no impact on our piracy cost estimate. The coefficient on trade is positive but insignificant. This suggests that time and dyad fixed effects do a good job in capturing variation in the conditions in shipping markets.

In column (6) of Table 4 we further address concerns about unobservable economic trends by incorporating a separate set of region specific time trends for each of the twenty-four regions from which shipping emanates (Eastern Africa, Southwest Asia, etc.).[32] Even with this rather saturated specification, the core finding regarding the effect of piracy attacks is robust, albeit with a somewhat smaller coefficient compared to column (2) of Table 3. Our core finding also holds up if we control for a separate time fixed effect for the region in which each shipping route starts and finishes.

Shipping rates fell considerably when world trade collapsed in Fall 2008. One way to see whether our results are robust to a break in trade patterns around this time is to have separate sets of dyad fixed effects before and after the Lehman Brothers collapse in September 2008. Column (7) in Table 4 shows that we still find a significant positive effect of attacks on shipping rates.

[32]This entails problems. The time trend for the Middle East, for example, will effectively capture part of the variation induced by piracy as most charters in this area cross the piracy area.

Alternative Measures of Vulnerability to Piracy Attacks In order to match the data on piracy attacks to the shipping contracts data, it is necessary to specify criteria according to which some routes are vulnerable to piracy attack. As there is some leeway in the choice of such criteria, we now present some further results which show that our results are robust to alternative ways of doing this. These are shown in Table 5.

Columns (1) and (2) study the robustness of our results to the computation of the maritime routes. Ships could be travelling alternative routes in order to avoid the Suez canal fees or the piracy region and 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 compared to a route using the Suez Canal (and thus 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 percent (column (1)) or 20 percent (column (2)) 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 3 column (2).

In column (3) we use a more narrowly defined piracy region focusing on the key choke point: the Gulf of Aden.[33] The result shows that piracy in the Gulf of Aden still has a significantly positive impact on shipping prices through that area. Again the magnitude of the effect of piracy is very similar to that reported in our core specification.

Column (4) explores variation in exposure to piracy risk by introducing an interaction between our treatment dummy and the share of a trade route that passes through the Somalia area rectangle. We expect piracy attacks to affect the daily charter rate more if a larger share of the charter goes through the piracy-risk area. Column (4) provides a test of this by including the interaction of the share and attacks in addition to attacks. As expected, the interaction term is positive and significant which implies that higher rates are paid on

[33] For the Gulf of Aden, the bounding box is given by latitude $\in [10.5, 17]$ and longitude $\in [40, 52.2]$. This is drawn as the dark blue area in Figure 2.

routes that are treated for longer. Conditional on going through Somalia the average trade route is susceptible to piracy for about 20 percent of its length with the maximum being 68 percent. The coefficient on the interaction implies that a route with maximum exposure would become 20 percent more expensive with the rise in piracy.

Column (5) includes only the interaction term between the share of a route through the piracy area with the number of attacks as a measure of treatment. The rationale here is to drop the correlated attacks variable to get a better idea of the magnitudes involved. The coefficient is highly significant. The effect of an increase in number of attacks after May 2008 on shipping rates for the average treatment share is 7.92 percent, which is close to our other estimates.

Columns (6) and (7) present the results from a similar exercise to that conducted in columns (4) and (5). The key difference is that we now allow there to be time-variation in the maritime area that is considered to be affected by piracy. This addresses a potential concern that the choice of the broad Somalia box as our piracy area is somewhat ad-hoc. We generate time variation in the piracy area by computing the convex hull that is spanned by the coordinates of all the piracy attacks that had occurred up to each year inside the rectangular area which we specified for Somalia above (the shaded area in Figure 2).[34] We then compute the share of a shipping route that crosses each of these convex hulls. This gives us time-variation in the share of a shipping route that is affected by piracy. Using this, we can conduct the same exercises as we reported in columns (4) and (5) of Table 5. The results obtained are very similar suggesting that our initial way of capturing the risk of piracy is robust.[35]

[34]We are grateful to a referee for suggesting this exercise. The convex hulls for 2005 and 2010 are plotted in figure A3.

[35]This is perhaps not too surprising given that the maritime insurance industry considers almost the entire Indian ocean, similar to our Somalia bounding box, to be a war risk area from early 2009 onwards.

3.5 Composition Effects and Re-routing

We now explore the possibility that, as well as affecting costs, piracy attacks also changed the desirability of shipping on routes affected by piracy.

Effects on Shipping Piracy attacks could be a deterrent to shipping goods through areas that are susceptible to piracy attacks. We need to be able to rule this out, because if piracy was positively correlated with the quantity shipped, the observed higher shipping costs may simply reflect increased demand on this particular route. We consider two dimensions in which piracy could affect shipping other than increasing the cost of shipping. First, piracy could directly affect the amount of traffic on piracy routes. Second, piracy could affect the composition of ships going through the piracy areas.

Data on passages through the Suez canal offers a way to analyze the impact of piracy on trade volumes. We obtain 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 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 from August 2007 to August 2008, the latter still being before 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

$$Cargo_t = \lambda_0 + \lambda_1 a_t + \lambda_2 Lehman_t + \lambda_3 t + \eta_t. \tag{7}$$

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

The results from running (7) with and without the Lehman dummy are in columns (1) and (2) of Table 6. 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 percent 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 suggest that piracy did not have a significant 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 a negative effect on trade of up to 3.5% which is in line with the Feyrer (2009) estimates of the effect of transport costs on trade.[36] Feyrer's estimates suggest that

[36] The average traffic pre May 2008 was $43,000$ metric tons. The change in the number of attacks was 14.33. 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 $1.1 + \frac{1.96 * 36.9 * 14.33}{43000} = 3.5\%$.

an increase of trade costs by 8% would yield a decrease in trade between 1.6% and 4%. As we cannot identify the effect on trade we therefore use Feyrer's estimates in an extension to our core welfare calculations.

We regard these results as being in line with a recent World Bank report that uses trade value data to identify the welfare effects of piracy. The report attempts to estimate the effect of piracy on trade from gravity equations but finds only marginally significant and generally inconclusive results.[37]

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:

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

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 result is reported in column (3) of Table 6. While there is a negative coefficient on Somali piracy attacks, this coefficient is not significant at conventional levels. Thus, there does not seem to be any evidence of substitution in ship size in response to piracy.

[37]See World Bank (2013). This is not mentioned in the body of the report. However, the main result and robustness table show that only four out of eleven estimated coefficients have the right sign and are significant. The only coefficient that is significant at the 5 percent level has the wrong sign.

4 The Welfare Cost of Piracy

We now discuss what our results imply for the welfare cost of piracy. Our approach is distinct from existing estimates such as One Earth Future Foundation (2010, 2011) since we have estimated the impact of piracy on shipping costs directly rather than using an accounting approach. We also adopt an explicit welfare criterion which recognizes that piracy creates a transfer from consumers of traded goods (who ultimately bear the cost) to pirates. We compare making a transfer via piracy to the cost of making a more efficient transfer to the same group via a tax. However, we acknowledge that not all costs are necessarily captured by the impact of piracy on shipping costs and will consider the sensitivity of the estimates to such concerns.

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.

Let Δ denote the cost increase per unit of shipping due to piracy. Part of this cost increase is a transfer to pirates, $\tau(\Delta)$, to which we could attach a distributional "welfare" weight. It is somewhat debatable what this weight should be. Ransoms transfer income to a poor country (Somalia) but they go mainly to organized criminals. It is unclear how far these benefits trickle down to the wider Somali population.[38] We feel that it is best to be

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

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 is captured by the resources spent in the process of delivering the transfer.

In this vein, we use the following thought experiment. Imagine there were an efficient transfer scheme, t, to transfer money from final consumers to pirates. If we were to keep pirates indifferent but use the efficient transfer, what would be the difference in costs to consumers as between this hypothetical transfer and when the transfer is made by piracy?[39]

In order to understand this welfare loss we need to first describe demand for final goods as a function of shipping costs. Suppose that there demand for a composite traded good, X, whose transport 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.[40] Suppose that there is a representative consumer with utility $U(X)$ and additive quasi-linear utility.

Shipping costs influence demand through price adjustments. Denote demand for the final good as $\hat{X}(\psi + \phi)$. Where ψ is the cost of production and ϕ is the shipping costs per unit of the final good. Under piracy the shipping cost is

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

and under the efficient transfer scheme it is

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

[39]Of course, a tax would be costly to administer and we are not including this in our thought experiment. But neither are we including the costs to pirates of extracting the resource. We expect this to induce a downward bias in our estimates of the welfare costs.

[40]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 makes the two measures equivalent.

where c is the cost of shipping.

If we were able to replace predation with taxation, the required unit tax, t, would be given by

$$t\nu\hat{X}(\psi+\phi(t))=\tau(\Delta)\,\nu\hat{X}(\psi+\phi(\Delta))\,. \tag{8}$$

The left hand side of this equation shows total income from the tax. The right hand side shows revenue from predation. Importantly, $\Delta \geq \tau(\Delta)$, the cost incurred by ship owners is potentially larger than the revenue that pirates receive.

In this simple model the welfare loss caused by piracy is then given by

$$\begin{aligned} L(\Delta) \;=\;& \left\{U\left(\hat{X}(\psi+\phi(t))\right)-\hat{X}(\psi+\phi(t))\,[\psi+\phi(t)]\right\} \\ & -\left\{U\left(\hat{X}(\psi+\phi(\Delta))\right)-\hat{X}(\psi+\phi(\Delta))\,[\psi+\phi(\Delta)]\right\}. \end{aligned} \tag{9}$$

where demand is potentially smaller under higher shipping costs, $\hat{X}(\psi+\phi(\Delta)) \leq \hat{X}(\psi+\phi(t))$, because the price of the final good increases from $\psi+\phi(t)$ to $\psi+\phi(\Delta)$.

4.2 Benchmark Estimate

A benchmark (first-order) estimate of (9) can be found by ignoring any trade response (i.e. demand response by consumers). In this case $\hat{X}(\psi+\nu[c+\Delta])$ is completely inelastic and $t=\tau(\Delta)$. In this case equation (9) takes on the simple form:

$$L^1(\Delta)=[\Delta-\tau(\Delta)]\times\nu\hat{X}. \tag{10}$$

Estimates of equation (10) for the year 2010 are in column (1) of Table 7. Details of all calculations are in Appendix F. 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 by using the mean bulk ship speed (from Stopford, 2009) and the average length of the trip in the respective sample.[41] Panel B adds an estimate of the DWT×days that do not travel through the Gulf of Aden but through the Indian Ocean.

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 3 and our high estimate uses column (4) of Table 3. Panel B applies these numbers to trade through the Indian Ocean.

We illustrate our calculations of $L^1(\Delta)$ with the low estimate in panel A of Table 7. We use the coefficient in column (1) of Table 3 and the average rate charter rate of 0.4726. This yields the following estimate of total piracy costs:

$$\begin{aligned}\Delta \times \nu \hat{X} &= 0.082 * 0.4726 \times 30.3 * 646064000 \\ &= 758 \text{ million USD}\end{aligned}$$

for 2010.[42] The average ship had a cargo capacity of 47,000 DWT which implies a pirate cost of around 55,000 USD.

Our estimate of $\tau(\Delta) \times \nu \hat{X}$ is the sum of the gross ransoms paid less the costs incurred by pirates in generating these. The main problem with calculating total ransom payments is that not all ransom payments are observed. Depending on the assumptions made on the unobserved payments, total ransom amounts vary widely. The Oceans Beyond Piracy (2010) and Geopolicity (2011) report ransom amounts of up to 240 USD for 2010. A recent report by World Bank et al (2013) finds much lower numbers of between 70 million USD and 90 million USD for the year 2010. Another World Bank (2013) report finds that labour and capital costs leave a (political) rent of between 70 and 86 percent of revenues. With these estimates of revenues and rents we get a range of 50 million USD up to 205 million USD for

[41] 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.

[42] 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 increase the cost.

$\tau(\Delta) \times \nu\hat{X}$. For now we ignore the margin of uncertainty and pick a value in the middle of this range, 120 million USD.[43]

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.

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 70 percent.

One way to understand the welfare loss is to contrast expected ransoms faced by the shipping industry with the increase in shipping costs. In 2010 there were 18,000 vessels travelling through the Suez Canal. In that year, pirates made 50 successful attacks which generated up to 4 Million USD each. This implies an expected loss of up to $11,000$ USD per vessel compared to an increase in shipping costs of $55,000$ USD. Thus, the realized losses due to ransom payments were about five times lower than our most conservative estimate of the welfare loss per vessel. This a fundamental consequence of economic predation combined with private security investments as we discuss further below.

4.3 Extended Estimates

There are further reasons to believe that our estimates in column (1) of Table 7 are a lower bound on the true cost. We now consider two of these: (i) the possibility of a demand response which reduces trade and (ii) the possibility that only a fraction of the cost of piracy

[43] This is also consistent with the calculations at `http://www.goo.gl/5T9nW`.

is paid by the charterer.[44]

Allowing for the possibility of a demand response, we show in the Appendix F.2 that the welfare loss due to a decrease in trade can be approximated by a scaling factor on the estimate above, which depends on the elasticity of trade with respect to transport costs, $\hat{\eta}$, and is given by[45]

$$L^2(\Delta) = L^1(\Delta)\left[1 + \frac{1}{2}\frac{\Delta - \tau(\Delta)}{c+\Delta}\hat{\eta}\right]. \tag{11}$$

It is clear that $L^2(\Delta) > L^1(\Delta)$ as long as $\hat{\eta} > 0$.

There are several possible estimates of $\hat{\eta}$ that we could use. Recent estimates from Feyrer (2009), who uses the Suez Canal closure from 1967 to 1975 as a shock to distance, suggest that a value of $\hat{\eta}$ between 0.2 and 0.5 is reasonable. This is a little lower than the estimate found in the meta study by 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 7. This implies that $L^2(\Delta)$ is larger than $L^1(\Delta)$ by a factor of between 1.017 and 1.03, i.e. 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 7 with column (1).

Column (3) of Table 7 allows for the possibility that the increase in shipping rates fails to capture *all* of the additional costs imposed by piracy.[46] To obtain an upper bound on this we check what would happen if costs were split between the ship owner and charterer according to the "general average rule" as it is known in the shipping industry. This 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

[44] 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.

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

[46] For example, time charter rates do not cover fuel expenses. If bulk ships speed up or re-route due to piracy then this will not appear in the charter rate leading to an underestimate.

bears. Then if charter rates increase by Δ due to shipping costs the overall cost to the industry is given by $\frac{\Delta}{2\zeta-1}$.[47] This yields our third measure of welfare cost of:

$$L^3(\Delta) = \left[\frac{\Delta}{2\zeta - 1} - \tau(\Delta)\right] \times \nu \hat{X} \tag{12}$$

which is reported in column (3) of Table 7. The details on the calibration of ζ can be found in Appendix F.3. This leads to estimates that are somewhat larger than in column (1) of Table 7. For example, the low estimate allowing for general averaging is 130 percent higher. The resulting numbers give us a good idea of how much additional costs could be arising on the cargo owner's side in terms of additional fuel costs, insurance and re-routing.

Putting this together, our estimates for the Gulf of Aden and the Indian Ocean are between 1.1 billion USD and 3.7 billion USD. While the range of estimates is quite large, the comparison between these estimates and those of the transfer received by pirates is telling. We used a figure of 120 million USD for the transfer to pirates and the welfare costs would still be substantial even we used the highest estimate of 240 million USD from Oceans Beyond Piracy (2010) and Geopolicity (2011). And the welfare cost would be higher still using the smaller numbers on transfers to pirates in World Bank et al (2013). Hence, the results suggest a substantial welfare cost from piracy.

4.4 Predation versus Taxation

We can use the analysis above to calculate t - the tax rate on shipping through Aden which would yield the same revenue that is 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 who should receive the transfer would be impossible. However, it does provide another way of conceptualizing the costs involved.

[47] 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.

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 percent on chartering would be needed to generate a transfer of comparable magnitude to that generated by piracy. Even if we assume that a rent of 205 million USD was generated by piracy this would still imply a tax rate of only 1.4 percent. This contrasts with our estimates of the increase in shipping costs of between 8 and 12 percent. The predatory activity of the kind undertaken by pirates is between 5 and 16 times more costly as a means of transferring resources to pirates than taxation would be.

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 7, a conservative estimate of the costs of piracy to the shipping industry is about 1.05 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.[48] 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.

[48]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.

4.5 Investing in Security

Given the increases in shipping costs that we have found, the question arises of why piracy remains a threat. The question of how security is provided and the optimality of arrangements in place raises a range of issues which go beyond the scope of the paper. However, we briefly discuss some of the issues here and argue that, *prima facie*, there is evidence that there is currently scope for coordinating security.

The obvious course open to ship owners to reduce piracy risk is to make independent investments in defensive measures such as barbed wire, panic rooms and security crews for their ships. We would expect this to be done according to a cost-benefit calculation by each ship owner. Our estimates could be regarded as the expected hijacking costs if no defensive measures were taken.[49] In addition to ransom payments, attempted hijacks generate costs if ships are damaged after the hijacking, especially since pirates have to hold ships for long enough to establish their credibility. The risk of being captured for several months also increases the cost of recruiting crew members who demand a wage premium as compensation. Ransom negotiations for crew and ship are like an inefficient war of attrition which increases the cost of doing business and creates delay over and above the cost of the ransom.[50]

Given that no ship with security teams on board has been hijacked we consider now the costs arising when investments in security are decentralized.[51] From conversations with security firms, we know that they charge about 3000 USD for a security crew of four per day.[52] The guards typically board the vessel at key locations before entering the Indian Ocean. The boarding points are Sri Lanka, the Strait of Hormuz, Madagascar and an anchored vessel in

[49]In the interpretation of Jayadev and Bowles (2006) the welfare loss we capture is then a direct consequence of the guard labor needed to defend economic inequality.

[50]For an analysis of a closely 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.

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

[52]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.

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. In Table 7 we calculated costs which lie between 640 million USD and 2.4 billion USD for traffic through Aden. Taken at face value, it suggests a large loss due to decentralized decisiosn over the provision of security.

This apparent inefficiency is best explained as being due to externalities in protection decisions. There are two plausible externalities at work which have opposite signs. To the extent that being protected increases the chances that unprotected vessels are susceptible to attacks, there is a negative externality from investing in protection.[53] Alone, this might lead to excessive investments. However, investments in protection may reduce the overall level of piracy attacks by reducing pirate intensity. And this will tend to lead to too little investment.[54] Either way, this creates an argument in favor of coordinated action.[55] However, such coordination among a myriad of ship-owners will be difficult to achieve and our evidence suggests that externalities leading to free-rider problems may be important.

[53]Bandiera (2003) makes a similar point. 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).

[54]To illustrate this, consider the following simple model. Suppose that there is continuum of ship owners of size one indexed by $n \in [0, 1]$ and that each can eliminate the threat of piracy at cost f. Let the threat of any particular ship being attacked when $\hat{n}$ vessels are protected be $p(\hat{n})$. The loss from being attacked is $-\ell$. Now the equilibrium condition determining the fraction of vessels who choose to protect is

$$p(\hat{n})\,\ell = f.$$

For this to be a stable interior solution, we require that $p'(\hat{n}) < 0$. This says that (locally) having more vessels protected, reduces the likelihood of being attacked. The surplus maximizing level of protection maximizes

$$S(\hat{n}) = -\hat{n}f - (1-\hat{n})\,p(\hat{n})\,\ell$$

by choice of $\hat{n}$. And it is straightforward to see that at any stable interior decentralized outcome

$$S'(\hat{n}) = -(1-\hat{n})\,p'(\hat{n})\,\ell > 0$$

i.e., there is too little investment in protection.

[55]See Besley and Ghatak (2010) for development of this argument in relation to property rights enforcement. See Grossman (2002) for a theoretical argument relating to predation.

This apparent inefficiency due to uncoordinated protection notwithstanding, it does appear as if defensive measures in Somalia have been increasingly successful - the number of successful hijacks has declined by more than 70 percent between 2010 and 2012. But if this is indeed a result of greater investment in security, it means that the costs of piracy to the industry may not have actually declined. These costs of protection continue to be incurred even when there are few successful attacks. Indeed, the possibility of predation can impose welfare costs even as the revenue generated by that predation goes to zero.

There may also be a case for going beyond coordinated private security towards collective provision. Whether this is optimal depends on the technology, coordination among providers and possible scale economies from having vessels that specialize in protection (such as a Navy) as a means of protecting ships. Successful collective provision is likely to occur only if there is an agreed way to share costs. In this regard, it is worthwhile noting that currently member countries of the EU, 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.[56] Difficulties in agreeing ways of sharing costs is not a new issue 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?"

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.

[56] We discuss the additional costs that this might cause in the Appendix G.

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.

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 five times more costly. In the language of Olson (1993), pirates are roving bandits while the state is a stationary bandit and hence is in a better place to organize extraction at lower costs. But this requires some commitment power on behalf of a stationary bandit. Absent such commitment in the context of piracy, the shipping industry has started to invest in protection. The resulting reduction in pirate activity, however, is just a change in the way that the costs of piracy manifest themselves. Without a return to strong law and order in Somalia, it seems unlikely that the underlying welfare costs will disappear any time soon.

There are a number of insights from our findings which extend beyond the specific context that we study. The results suggest that there can be a substantial cost of predation even if the transfers that are generated are modest. There is a parallel here with the welfare cost of crime more generally. For example, a high perceived risk of burglary can encourage house holders to invest in private security which can lead to significant costs even if, as a consequence, burglars earn low returns from their activity. Thus, gauging the costs of predation and theft requires looking beyond the extent of the crime that actually occurs.

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] Aidt, Toke. S., (2003). Economic analysis of corruption: A survey. *Economic Journal* 113, F632–F652.

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

[4] Anderson, James E., and Oriana Bandiera (2006). Traders, Cops and Robbers. *Journal of International Economics*, 70(1), 197-215.

[5] Anderson, James E., and Eric van Wincoop, (2004). Trade Costs. *Journal of Economic Literature*, 42(3), 691-751.

[6] Anderson, James E., and Douglas Marcouiller (2004). Insecurity and the Pattern of Trade: An Empirical Investigation, *Review of Economics and Statistics*, 83, 342-352.

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

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

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

[10] 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.

[11] 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.

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

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

[14] Berman, Eli, Joseph Felter, Ethan Kapstein, and Erin Troland, (2012) Predation, Economic Activity and Violence: Evidence from the Philippines. NBER Working Paper No. w18375.

[15] Besley, Timothy and Hannes Mueller, (2012) Estimating the Peace Dividend: The Impact of Violence on House Prices in Northern Ireland. *American Economic Review*, 102(2): 810–33.

[16] 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.

[17] Blattman, Christopher and Edward Miguel, (2009). Civil War. *Journal of Economic Literature*, 48(1):3–57.

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

[19] 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.

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

[21] 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.

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

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

[24] Gambetta, Diego, (1996). The Sicilian Mafia: The Business of Private Protection. Harvard University Press (February 1, 1996).

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

[26] Grossman, Herschel, (2002). "Make us a king": anarchy, predation, and the state. *European Journal of Political Economy*, 18(1):31-46.

[27] Guidolin, Massimo and Eliana La Ferrara, (2007). Diamonds Are Forever, Wars Are Not. Is Conflict Bad for Private Firms? *American Economic Review*, 97(5): 1978-93.

[28] 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.

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

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

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

[32] Hummels, David, (2007). Transportation Costs and International Trade in the Second Era of Globalization. *The Journal of Economic Perspectives*, 21(3): 131-154.

[33] Jayadev, Arjun and Samuel Bowles, (2006). Guard Labor. *Journal of Development Economics*, 79: 328–348.

[34] Kalouptsidi, Myrto, (2014). Time to Build and Fluctuations in Bulk Shipping. *American Economic Review*, 104(2): 564-608.

[35] Keefer, Philip and Stephen Knack, (1995). Institutions And Economic Performance: Cross-Country Tests Using Alternative Institutional Measures, *Economics and Politics*, 7(3), 207-227.

[36] Mauro, Paolo., (1995). Corruption and Growth. *Quarterly Journal of Economics*, 110, 681–712.

[37] Mirza, Daniel and Thierry Verdier, (2008), International Trade, Security and Transnational Terrorism: Theory and Empirics, *Journal of Comparative Economics*, 36(2), 179-194.

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

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

[40] Olson, Mancur (1993). Dictatorship, Democracy, and Development. *American Political Science Review* , 87(3):567-576.

[41] One Earth Future Foundation, (2010, 2011). The Economic Costs of Maritime Piracy. *Working paper.*

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

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

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

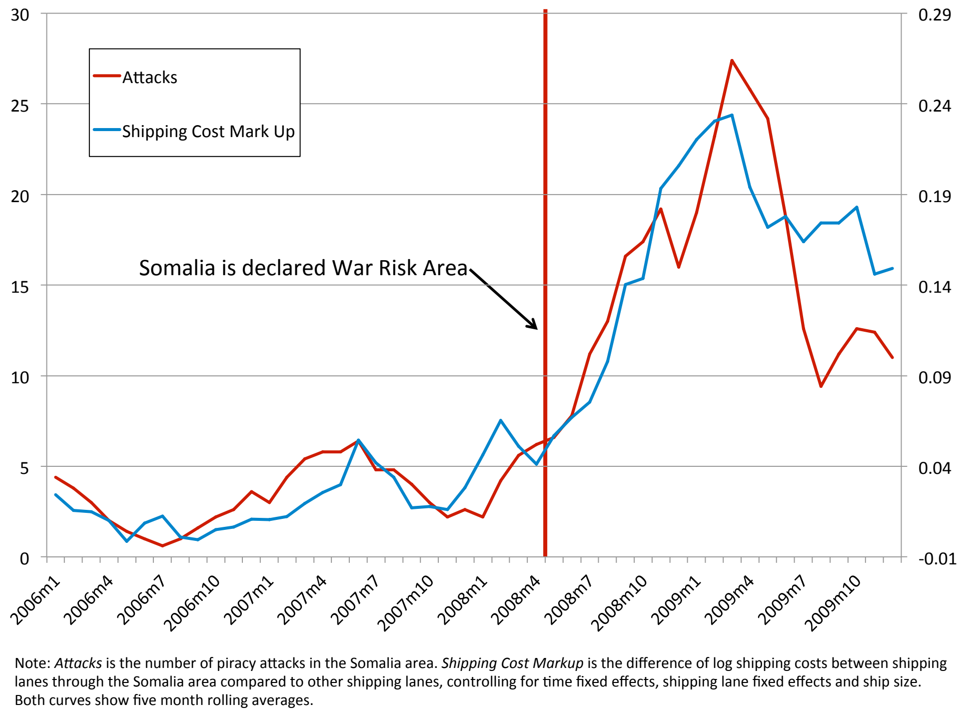
[45] UNCTAD (2009, 2010). Review of Maritime Transport. *Report by the UNCTAD secretariat*.

[46] Voors, Maarten, Eleonora Nillesen, Philip Verwimp, Erwin Bulte, Robert Lensink and Daan Van Soest, (2012). Violent Conflict and Behavior: A Field Experiment in Burundi. *American Economic Review*, 102(2):941-64.

[47] World Bank (2013) The Pirates of Somalia: Ending the Threat, Rebuilding a Nation. http://www.worldbank.org/africa/piratesofsomalia.

[48] World Bank, United Nations Office on Drugs and Crime and Interpol (2013) *Pirate Trails: Tracking the Illicit Financial Flows from Pirate Activities off the Horn of Africa.* Washington, DC: World Bank.

Main Figures



Note: Attacks is the number of piracy attacks in the Somalia area. Shipping Cost Markup is the difference of log shipping costs between shipping lanes through the Somalia area compared to other shipping lanes, controlling for time fixed effects, shipping lane fixed effects and ship size. Both curves show five month rolling averages.

Figure 1: Non-Parametric Visualization of Piracy Effect on Chartering Rates

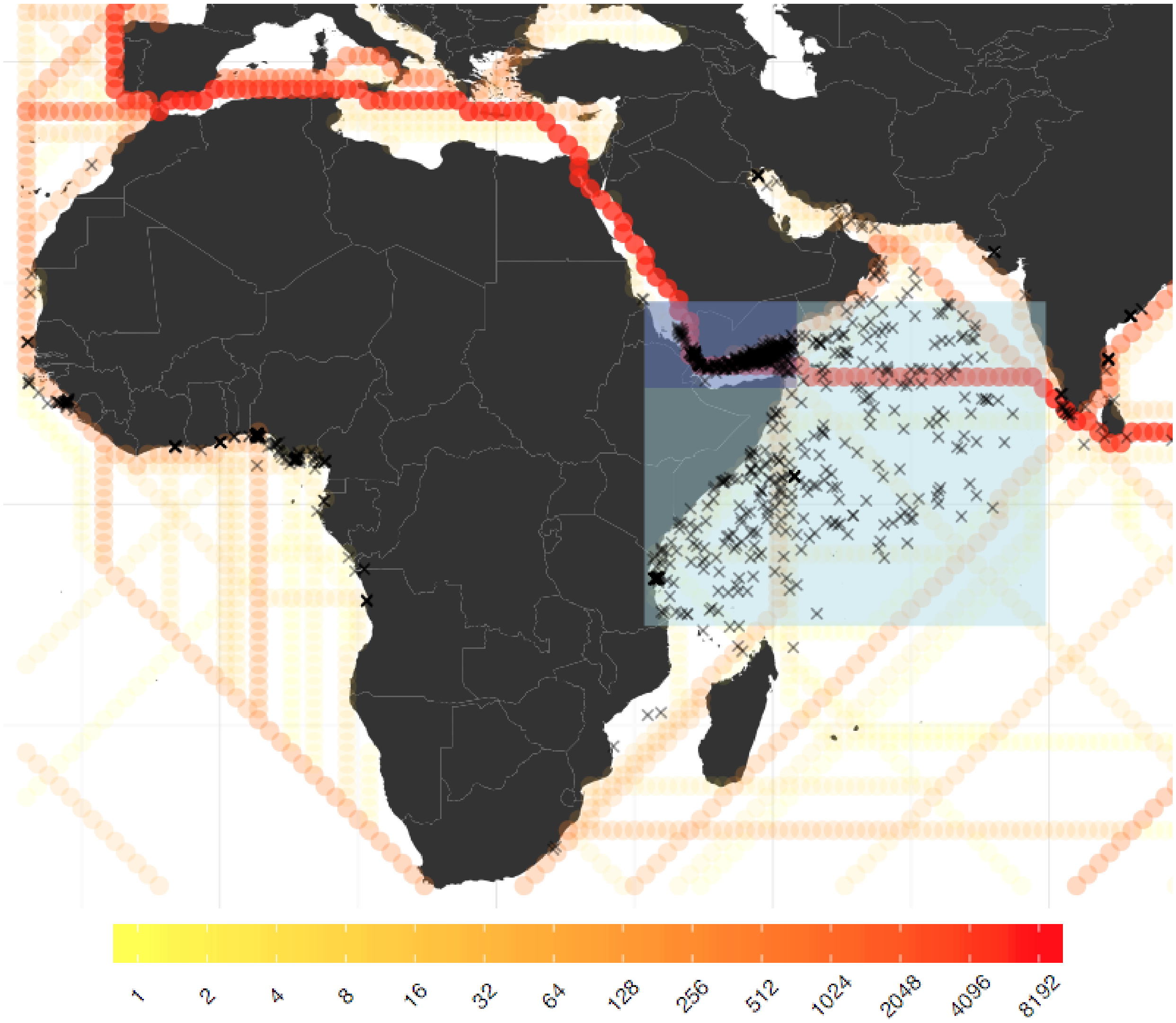


Figure 2: Calculated Shipping Lanes and Treatment Areas
Note: The light shaded rectangle is the "Somalia" treatment area, while the darker shaded area is the "Gulf of Aden" treatment area. The location of attacks is indicated by a cross. The circles indicate the shipping lanes, the colouring of which is proportional to the number of observation on each shipping lane according to the continuous colour scheme.

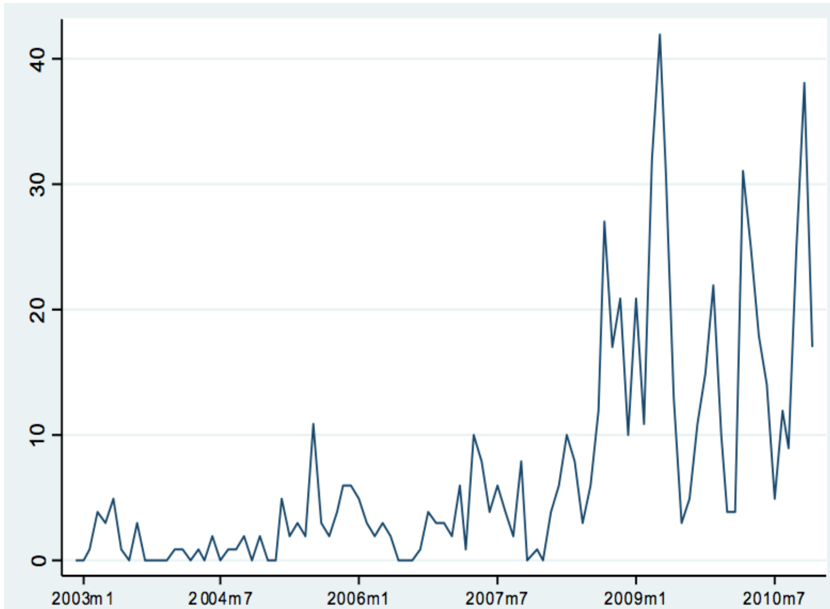


Figure 3: Time Series of Attacks in Somalia

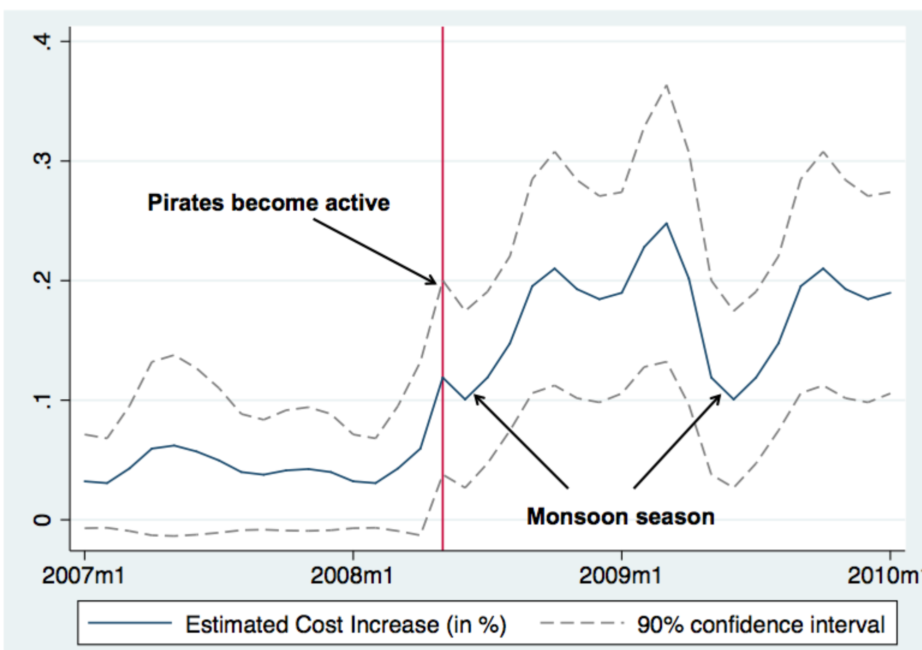


Figure 4: Shipping Cost Prediction of Pirate Activity and Monsoon Season

Main Tables

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

Note: Table shows the mean of attacks in the Somalia area in the periods 2002-2007 and 2008-2009.

Table 2: Piracy Attacks and Shipping Costs - Simple Difference in Difference

charter rate per DWT on routes	(1) before May 2008	(2) after May 2008	(3) difference
that do not pass the piracy area	0.486	0.386	0.100
	(0.00306)	(0.00329)	(0.00450)
that pass the piracy area	0.480	0.454	0.026
	(0.00415)	(0.00653)	(0.00781)
difference	0.006	-0.068	**0.074**
	(0.00516)	(0.00731)	(0.00894)

Notes: Charter rates are given in US dollars per deadweight tonnage (DWT).

Table 3: Main Results

	(1) Baseline	(2) Adding controls	(3) Post May 08	(4) War Risk	(5) Wind-speed
attacks (Somalia)	8.204**	8.438**	3.862***		
	(3.558)	(3.542)	(1.057)		
war risk area				12.332*	2.183
				(6.924)	(5.556)
calm winds * war risk area					18.254***
					(4.407)
calm winds					-0.036*
					(0.021)
ballast bonus per DWT		-0.001	-1.509***	-0.001	-0.001
		(0.001)	(0.529)	(0.001)	(0.001)
ship age		-0.614***	-0.754***	-0.613***	-0.611***
		(0.098)	(0.191)	(0.098)	(0.098)
handysize	0.622***	0.637***	0.627***	0.639***	0.638***
	(0.031)	(0.031)	(0.030)	(0.030)	(0.030)
handymax	0.400***	0.403***	0.372***	0.404***	0.404***
	(0.031)	(0.036)	(0.031)	(0.036)	(0.036)
panamax	0.149***	0.150***	0.177***	0.152***	0.152***
	(0.018)	(0.012)	(0.014)	(0.012)	(0.012)
capesize	-0.039	-0.051*	-0.082	-0.050*	-0.050*
	(0.037)	(0.029)	(0.067)	(0.030)	(0.030)
Observations	23679	23679	9530	23679	23679
R-squared	.851	.856	.829	.856	.856

Notes: All regressions include dyad fixed effects, ship-size controls and time fixed effects. Robust standard errors adjusted for two-way clustering on the origin and destination country for each voyage are in the parentheses with stars indicating *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. The dependent variable is the log of the charter rate in US dollars per dead-weight tonnage (DWT). 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 $DWT \leq 35000$. "Handymax" are ships with $35000 < DWT \leq 55000$. "Panamax" are ships with $55000 < DWT \leq 80000$. "Small capesize" are ships with $80000 < DWT \leq 150000$ (omitted). "Capesize" are ships with $DWT > 150000$. "Ballast bonus" is a payment that compensates the ship owner for travelling without cargo on return. "War risk area" is a dummy that indicates whether the area was defined as a war risk area by the Maritime Insurer's Joint War Committee. The coefficient on the attack variables and of the war-risk and wind-interactions are multiplied by 100 for clearer exposition.

Table 4: Robustness Checks - Modelling Expectations and Macroeconomic Controls

	Expectations			Macroeconomic Controls			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	EM	EM (Seasonality)	Google Searches	GDP	Trade	Trends	Lehman Break
forecasted attacks (EM)	9.225*	8.747**					
	(5.539)	(3.709)					
Google Searches "Somalia Piracy"			0.502**				
			(0.200)				
attacks				8.449**	8.385**	5.833**	2.876**
				(3.545)	(3.268)	(2.490)	(1.330)
annual GDP growth origin region				0.024			
				(0.022)			
annual GDP growth destination region				-0.005			
				(0.015)			
monthly trade on dyad					0.008		
					(0.005)		
region time trend	No	No	No	No	No	Yes	No
post Lehman dyad fixed effect	No	No	No	No	No	No	Yes
Observations	23679	23679	21625	23679	21469	23679	23282
R-squared	.855	.856	.84	.856	.85	.86	.845

Notes: All regressions include dyad fixed effects, ship-size controls and time fixed effects. Robust standard errors adjusted for two-way clustering on the origin and destination country for each voyage are in the parentheses with stars indicating *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. The dependent variable is the log of the daily charter rate per deadweight tonnage (DWT). 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. Columns (1) and (2) use alternative models to forecast piracy attacks. We use a simple Markov chain model for column (1) and a Markov chain model that accounts for seasonality in column (2). Ship controls are dummy variables classifying the ship size in terms of DWT and contain the age of the ship and the size of the "Ballast bonus" for a particular voyage. Monthly trade on dyad is the log of the value of monthly trade on a dyad as obtained from the Export time-series from the IMF direction of trade database. For dyads where trade is zero, this is coded as a zero. The coefficients on the attack and news are multiplied by 100 for clearer exposition.

Table 5: Robustness Checks - Assignment of Routes, Treatment Areas and Intensity

	Assignment of Routes		Treament Areas				
	(1) Rerouting 10%	(2) Rerouting 20%	(3) Only Aden	(4) Fixed Area	(5) Fixed Area	(6) Varying Area	(7) Varying Area
attacks (Somalia)	9.841***	8.529***		1.911	4.441		
	(3.135)	(3.077)		(4.479)	(3.222)		
attacks (Aden)			7.780*				
			(4.375)				
share of route through piracy area * attacks				29.012*	20.586*	36.142***	40.363***
				(16.157)	(11.272)	(13.557)	(10.797)
share of route through piracy area					0.495		0.412
					(0.849)		(0.816)
Observations	23679	23679	23679	23679	23679	23679	23679
R-squared	.855	.855	.855	.856	.856	.856	.856

Notes: All regressions include dyad fixed effects, ship-size controls and time fixed effects. Robust standard errors adjusted for two-way clustering on the origin and destination country for each voyage are in the parentheses with stars indicating *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. The dependent variable is the log of the daily charter rate per deadweight tonnage (DWT). 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. Columns (6) and (7) present the results when we use time-varying piracy areas obtained from the year-on-year convex hulls that are spanned by the geo coordinates of the attacks that have occurred up to each year. Columns (4) and (6) test whether the share of a ships journey through maritime areas affected by piracy has an independent effect, while columns (5) and (7) present results when using the continuous measure of the share of route through the piracy area interacted with attacks as a control. The coefficients on the attack variables and war risk dummies are multiplied by 100 for clearer exposition.

Table 6: Extended Results - Suez Canal Traffic

	Suez Canal Traffic		Ship Size
	(1) Basic	(2) Lehman Break	(3) from Chartering Contracts
attacks (Somalia)	-12.015***	-2.296	
	(2.962)	(1.553)	
cargobreak		-0.432***	
		(0.025)	
attacks (Somalia)			-293.468
			(812.198)
linear trend	Yes	Yes	.
route fixed effect	.	.	Yes
month fixed effect	.	.	Yes
Observations	108	108	12753
R-squared	.638	.923	.482

Notes: Robust standard errors are reported. The stars indicate *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. The dependent variable is the log of cargo traffic in a particular month through the Suez Canal. The variable "cargobreak" is an indicator that is equal to 1 after the break in cargo trade volumes following the Lehman brothers collapse in November 2011, "attacks" measures the number of attacks in the Somalia area in a given month. The coefficient on the attack variable is multiplied by 100 for clearer exposition.

Table 7: The Welfare Cost of Piracy in 2010

Panel A: Aden	(1) L1 (in million USD)	(2) L2 (in million USD)	(3) L3 (in million USD)
low estimate	638	649	1495
high estimate	1073	1103	2422
Panel B: Aden and Indian Ocean	(1) L1 (in million USD)	(2) L2 (in million USD)	(3) L3 (in million USD)
low estimate	1093	1113	2464
high estimate	1700	1749	3757

Notes: Calculations are discussed in section 4 and the apprendix E. 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.

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

[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`.

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 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)

[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`

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 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

[59]The data can be accessed via `http://www.goo.gl/DM8Ol`.

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]

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

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

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

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

[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 assumption of constant pass-through implies $\mu''(p_{dt}) = 0$. In the constant elasticity world used in the welfare calculations, for example, we have $\mu'(p) = -\frac{1}{\epsilon}$. 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. $E[a_{t+1}] = a_t$. 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:

$$\begin{array}{ccc} & \ell_{t-1} = W & \ell_{t-1} = S \\ \ell_t = W & p & 1-q \\ \ell_t = S & 1-p & q \end{array}$$

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

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

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

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

and therefore depend on parameters in θ.

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

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

and

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

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

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

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

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

[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.

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 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

[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).

[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.

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.

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

[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.

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:

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

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:

[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:

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

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

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

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 (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

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

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

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

[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.

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.

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.*

References for Online Appendix

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

[2] Fabinger and Weyl (2012) Pass-Through and Demand Forms. Mimeo. University of Chicago.

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

[4] 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.

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

[6] One Earth Future Foundation, (2010, 2011). The Economic Costs of Maritime Piracy. *Working paper.*

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

[8] UNCTAD (2009, 2010). Review of Maritime Transport. *Report by the UNCTAD secretariat.*

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

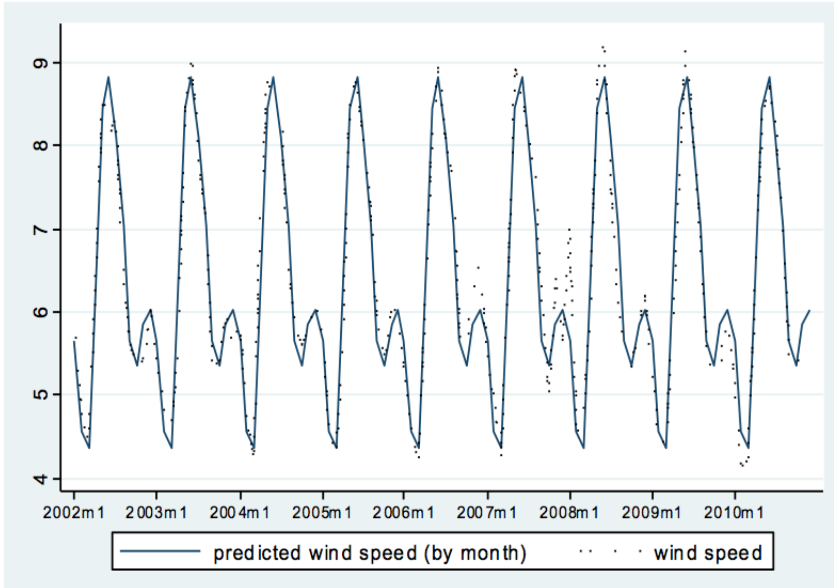


Figure A1: Wind Speed in the Somalia Area

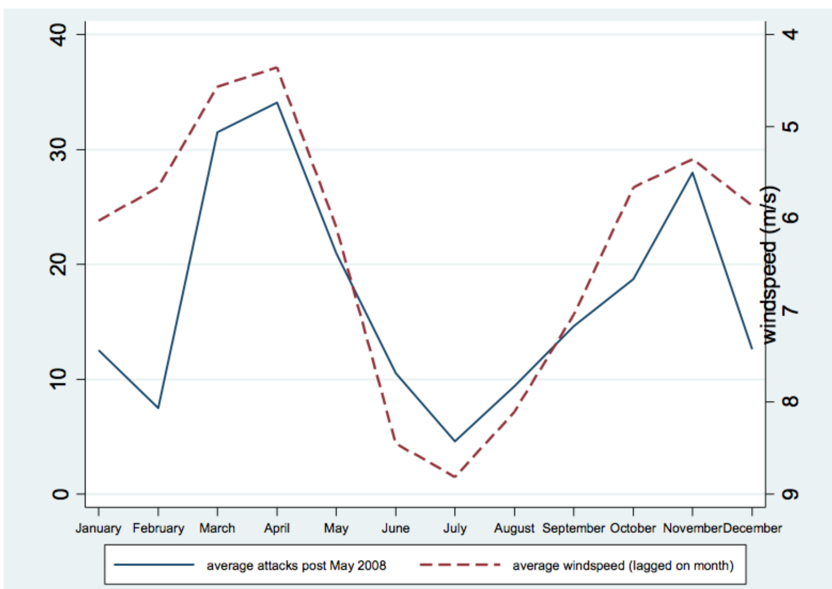


Figure A2: Wind Speed and Attacks in the Somalia Area

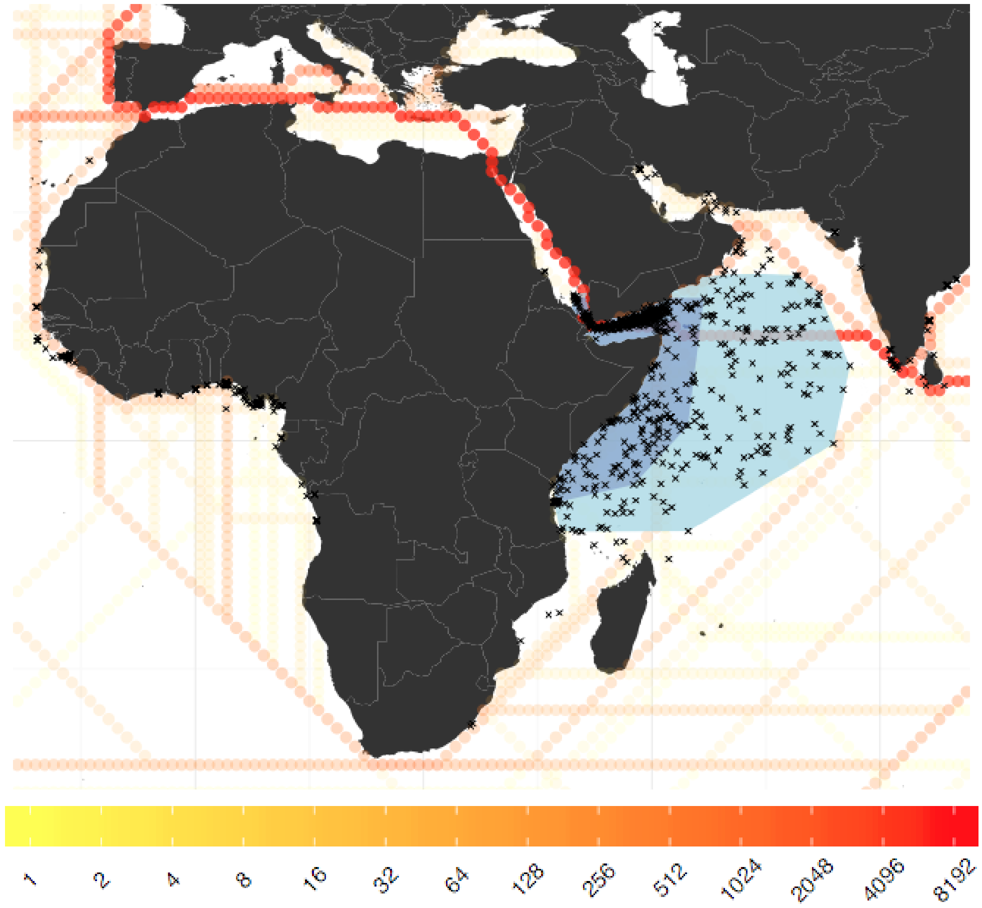


Figure A3: Calculated Shipping Lanes and Treatment Areas Based on Convex Hulls
Note: The dark shaded area on the interior is the convex hull spanned by all attacks up to 2005, while the bigger light shaded area is the convex hull spanned by all attacks up to 2010. The location of attacks is indicated 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)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Lagged Attacks	AR(2)	EM	EM (seasonal)	Somali Piracy	Somali Piracy	Gulf of Aden	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.