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The Trade Consequences of Maritime Insecurity: Evidence from Somali Piracy

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Abstract

In the past decade (2000–2010), pirates from Somalia have carried out thousands of attacks on cargo ships sailing through the Gulf of Aden and the Indian Ocean, causing what others have identified as significant damage to maritime trade. In this paper, we use variations in the spread and intensity of Somali piracy to estimate its effect on the volume of international trade. By comparing trade volume changes along shipping routes located in pirate waters to those that are not, we estimate that Somali piracy reduced bulk commodities trade passing through the Gulf of Aden by 4.1% per year from 2000 to 2010. We find smaller reductions in total trade, consistent with the fact that not all goods are shipped by sea or are targets of pirate attacks. While our estimates suggest that the trade costs of piracy are much lower than what has been suggested in the existing literature, we find that they remain significant and unevenly distributed, with five countries and the EU shouldering 70% of the total costs.

1. Introduction

Maritime piracy around Somalia has emerged over the past two decades (1990–2010) as a legitimate threat to international trade. The combination of weak governmental institutions, a natural geographic choke point in the Gulf of Aden, and a significant flow of ships through the Gulf has allowed pirates to establish safe harbors from which to attack a plethora of available targets. Successful attacks have significant consequences: hijacked ships, kidnapped crews, expensive ransom negotiations and loss of life. As merchant ships are attacked and trade flows disrupted, the cost of transporting goods through pirate waters increases, possibly discouraging trade through these regions. This problem has global dimensions. Annually, we estimate that 12% of world trade passes through the Suez Canal and is therefore affected by this threat. Countries in the Indian Ocean region, whose ports are in relatively close proximity to the Gulf of Aden, ship as much as 60% of their imports through pirate-infested waters. These countries are potentially exposed to significant trade disruptions and could be the victims of pirate-induced price distortions in their traded goods, with consequent welfare implications.

In this paper, we lay out a simple model of bilateral trade where piracy increases trade costs. From this, we derive an augmented gravity equation to estimate the effect of pirate activity on trade volumes. Using a global panel data set combining information on bilateral volumes of trade and on reported pirate attacks, we first study how

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annual trade between pairs of countries that transfer goods through pirate-infested waters is affected by the intensity of piracy. We then compare this effect to trade between country pairs that arguably use other shipping lanes that are free of Somali pirates.

We estimate the cost of piracy in two ways. We first follow the existing literature in measuring pirate activity as the total number of pirate attacks in a given year that took place around Somalia. This includes successful hijackings and boardings as well as attempted boardings and cases where a ship was fired upon. A drawback of this estimation strategy is that the number of attacks could be endogenous to trade for a number of reasons including reverse causality and omitted factors. For instance, if more ships transit through an area, the probability of an encounter mechanically increases. Alternatively, if ships hire (unobserved) protective military vessels in response to high piracy risks, we could observe fewer attempted attacks, even though shipping costs would have increased. For this reason, we use the geographic reach of pirates as a second measure of pirate activity, which has the advantage of being generally unrelated to the volume and frequency of international trade. From the early 2000s until 2009, Somali pirates significantly improved and refined their equipment and organizational structures, often by adopting more sophisticated weapon and transportation systems. Technological improvements have allowed pirates to attack further away from their coastal bases in Somalia, increasing considerably the geographic spread of pirate-infested waters and the amount of time ships spend transiting through those waters, thus raising trade costs.

Our point estimates indicate that piracy originating from Somalia and occurring in or around the Gulf of Aden significantly reduces trade between country pairs that ship goods though the Gulf. The reduction in the volume of bilateral trade owing to the increase in attacks and in pirate reach between 2000 and 2010 is estimated to be 1.7–1.9% per year. This estimate takes into account all tradeable goods, even those less susceptible to maritime transport. Trade in bulk commodities, which are almost exclusively shipped by sea and are the most likely to respond to trade frictions because of their larger elasticity of demand, is estimated to fall an average of 4.1% per year. In addition to giving larger point estimates, a number of robustness tests suggest that the results based on bulk commodities are also more robust to different model specifications.

We also carry out a heterogeneity analysis to understand the variation in trade costs along several relevant dimensions. We find that piracy in the Gulf of Aden reduces trade between countries that are separated by relatively short distances, but not between countries that are far apart. This evidence is consistent with shorter routes witnessing a larger relative increase in trade costs given that a bigger fraction of the total distance is traveled through pirate waters. This is also consistent with more distant country pairs having other routing possibilities that avoid the Gulf of Aden. When considering which nations are most affected by the piracy problem, we find that the effect of piracy does not vary systematically with the income of a trading partner.

Applying our estimates to the value of trade moving through the Gulf of Aden suggests that no country—including those with a significant share of trade moving through Aden—loses more than 2% of trade value because of piracy. However, in our view it would be incorrect to conclude that the costs from piracy are negligible. When considering the *absolute value* of trade losses, we estimate an average annual loss of US$25 billion over the 2000–2010 period, with most of that accruing to a handful of countries. In particular, our estimates suggest that four countries and the EU shouldered 70% of the total costs of piracy, with the EU in particular losing an annual US$11 billion in trade, or 44% of the total cost.

Our paper provides important and robust evidence that the threat of violence and, more generally, the possibility of disruptions in the transportation network have a negative effect on trade. In this regard, the paper shares an important commonality with Anderson and Marcouiller (2002), Nitsch and Schumacher (2004), Blomberg and Hess (2006), Mirza and Verdier (2008) and De Sousa et al. (2008), which find an effect of violence and terrorism on transnational commerce.

From a methodological viewpoint, our paper adds insights to the gravity equation literature by emphasizing the role of multilateral resistance terms in estimations of time-varying trade costs. Since the seminal contribution of Anderson and Van Wincoop (2003), it is well known that omitting the multilateral resistance terms from gravity estimations leads to biased estimates. However, owing to data limitations or computational constraints, it is not uncommon in panel datasets to account for the multilateral resistance terms using country rather than country–year fixed effects. As our results show, this substitution is problematic for time-varying trade costs because of the likely existence of common trends between the uncontrolled time dimension of a country's multilateral resistance and the bilateral trade costs.[1]

Our paper joins an economic literature assessing modern piracy.[2] Besley et al. (2015) estimate that the increase in pirate attacks in 2008 caused an increase in shipping costs between 8% and 13% for bulk goods traveling through the Gulf of Aden. Bensassi and Martínez-Zarzoso (2012) study the effect of piracy on the volume of international trade between Europe and Asia, and find that exports fell by 11% for every 10 ships that are hijacked by pirates from Somalia, Southern or South-Eastern Asia.[3] A recent report by the World Bank (2013) focuses strictly on Somali piracy. Using a methodology similar to ours to identify trade routes affected by piracy, the study exploits a difference-in-differences strategy on a sample of 150 countries, and finds that the trade flows of affected countries fell by 7.4% after 2006 owing to Somali piracy. This corresponds to an increase in trade costs of 0.74–1.49%. We improve on the strategy in the World Bank report by using a rich structure of fixed effects to account for country-specific changes in the patterns of trade over time (i.e. multilateral resistance terms), and by using measures of piracy intensity (i.e. number of attacks and pirate reach) which better capture the significant ramp-up of pirate activity after 2006.

The remainder of this paper proceeds as follows. Section 2 describes maritime piracy in the Gulf of Aden and discusses the mechanisms through which piracy may affect trade volumes and trade costs. Section 3 lays out the empirical model for bilateral trade. Section 4 describes the data sources and variable construction, while Section 5 presents our results on the impact of piracy on international trade. Section 6 concludes.

2. Background

Spread of Somali Piracy

Piracy affects a large number of countries in the world, especially around the tropics. The concentration of piracy in these regions can be seen in Figure 1, which maps all recorded instances of pirate attacks collected by the International Maritime Bureau from 2000 to 2011. The Horn of Africa around the Gulf of Aden is the site for a significant number of those attacks. Other areas with a high frequency of attacks include

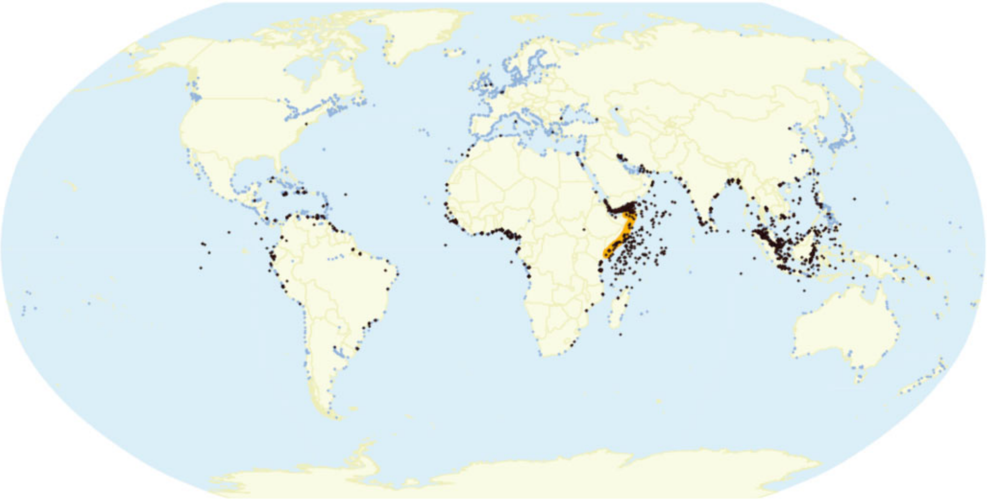

Figure 1. The Incidence of Pirate Attacks

Note: The geographic locations of pirate attacks that occurred during the period 1991–2010 are represented by dark dots. Light colored dots identify the main maritime ports by country.

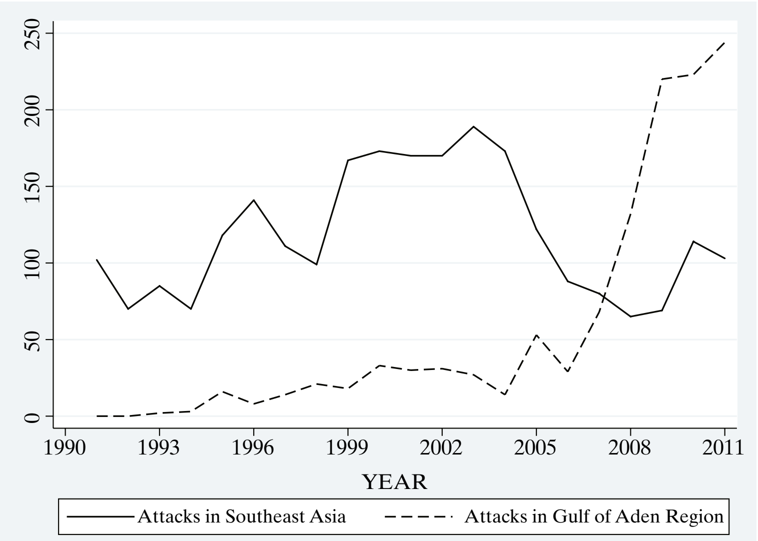

Figure 2. Total Number of Pirate Attacks by Year and Region

Note: The time series displays the total number of attacks per year assigned to Somalia or the Strait of Malacca as documented in Table 2.

the Malacca Strait, the Gold Coast around West Africa, and the Gulf of Bengal. The emergence of widespread piracy events around Somalia is relatively recent. Figure 2 plots the time series of attacks around the Gulf of Aden and the Malacca Strait over the period 1991–2011.[4] While Indonesian piracy has been active and relatively constant for at least two decades, Somali piracy did not occur in large numbers until 2005.[5]

A key characteristic of Somali piracy is that, in a short amount of time, it has experienced a significant technological evolution.[6] Initially, pirates operated *dhows* or fishing boats to assault vessels that came too close to the Somali coast. As commercial vessels improved their defenses and stayed away from the Horn of Africa, pirates enrolled better arms and faster and more powerful boats, which allowed them to seek targets further afield (Tsvetkova 2009). As operations became more organized and better funded, pirates invested in a "mother-ship" strategy involving a large pirate ship serving as a base for a number of speed boats located deep in the open ocean (Treves 2009). Upon finding a suitable target, pirates would board the speedboats and quickly approach and attempt to hijack the target ship. If captured, the vessel would then be directed to a pirate safe haven in Somalia, where it remained while ransom negotiations took place (Shortland and Vothknecht 2011). The result of this technological and organizational evolution is that piracy increased dramatically in intensity, violence and geographic spread. As Figure 3 shows, all reported pirate attacks occurred within 500 km of the Somali coast until 2003. Starting in 2004, attacks were taking place between 500 and 1000 km from the coast and, after 2005, some attacks were taking place 1200 km from the Somali coast. As the reach of piracy extended further and further into the Indian Ocean, ships were spending more and more of their travel time in "pirate waters."[7]

While both the number of attacks and the geographic spread of piracy were increasing in the second half of the decade, the timing between the two dimensions of expansion differed somewhat. Figure 4 graphs the monthly counts of attacks, the distance of the furthest attack from a Somali port by month and year, and (with a dashed line) the maximum distance in km away from Somalia that pirates had attacked up to that point—a distance that we refer to as *Reach*. The frequency of attacks was highest in the 2007–2009 period. In contrast, the ability of pirates to reach targets increased the fastest in the 2005–2007 period.

Cost of Piracy

Piracy imposes two types of costs on maritime carriers. A direct cost is accrued in the eventuality of pirate capture. Once a ship is captured, it is often driven to the Somali coast where the cargo, crew and ship are taken hostage, often for long periods of time, while a ransom is negotiated.[8] Most hijacking cases are resolved with the ship, crew and cargo being returned to the owner once the ransom has been paid. Sometimes captured vessels are retained and turned into pirate mother-ships, or crew members are killed or die in captivity.[9]

The probability that a hijacking occurs is generally quite small, although not negligible. For example, in 2009, it is estimated that only 0.2% of the ships passing through the Gulf of Aden were boarded by pirates (Gilpin 2009). Nonetheless, the substantially high costs of capture impose increased *operating* costs on all transiting ships. Ships transiting through pirate waters must pay higher risk premia on insurance, as well as on wages and benefits to crews as a result of the risk of being attacked, taken hostage or even killed.[10] They must also engage in other defensive measures such as hiring security forces, increasing travel speed in pirate waters with consequent increases in fuel use and modifying ships to make them less likely to be hijacked (De Groot et al. 2012). Besley et al. (2015) estimate that shipping costs through the Gulf of Aden have increased by 8–13% following the increase of pirate activity.[11]

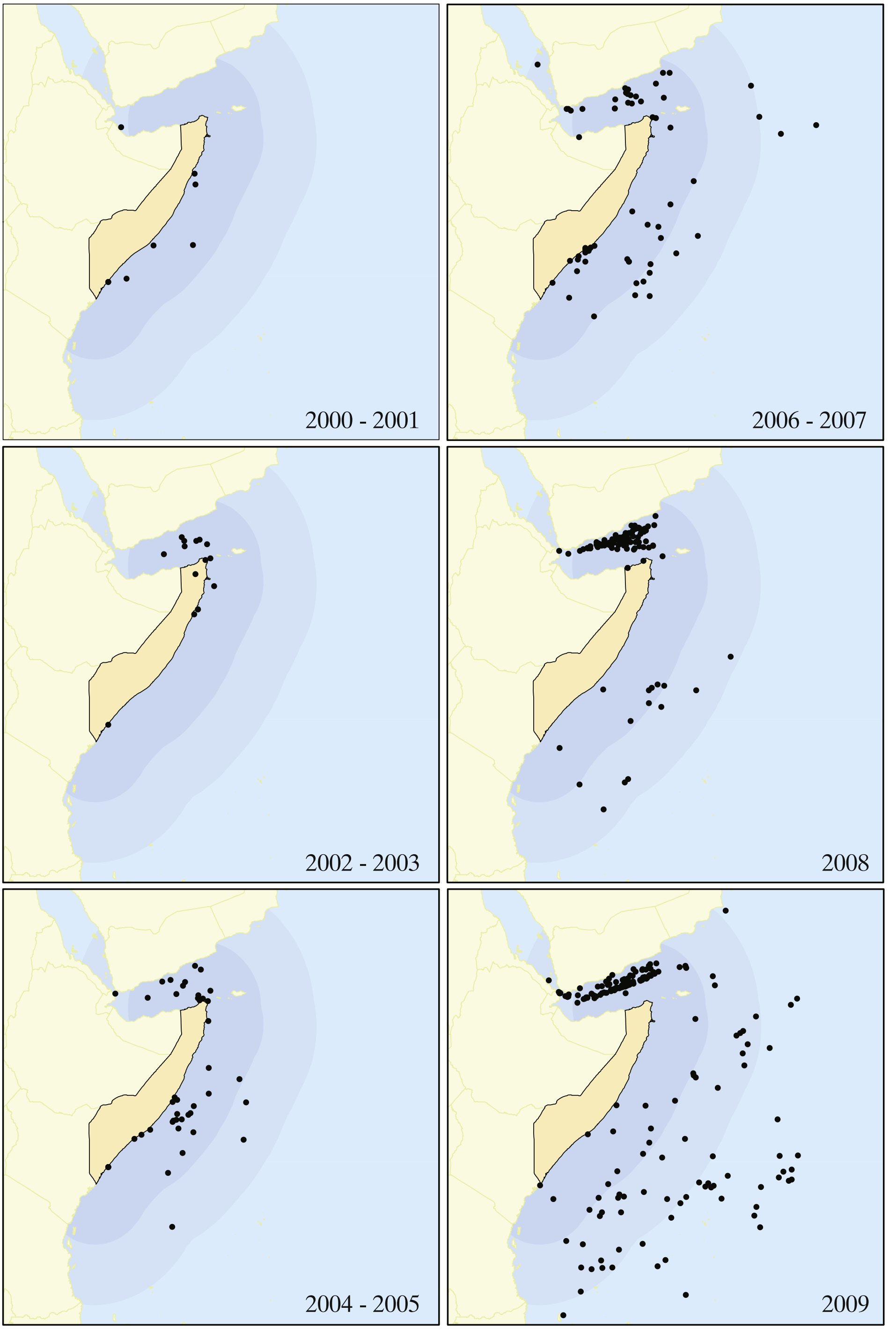

Figure 3. The Geographic Reach of Somali Attacks Over Time

Note: The figure illustrates the expansion of maritime piracy in the Horn of Africa near Somalia (drawn in black contour). Each black dot corresponds to the location of individual pirate attacks. The concentric sea zones off the coast of Somalia mark the 500 and 1000 km borderlines respectively.

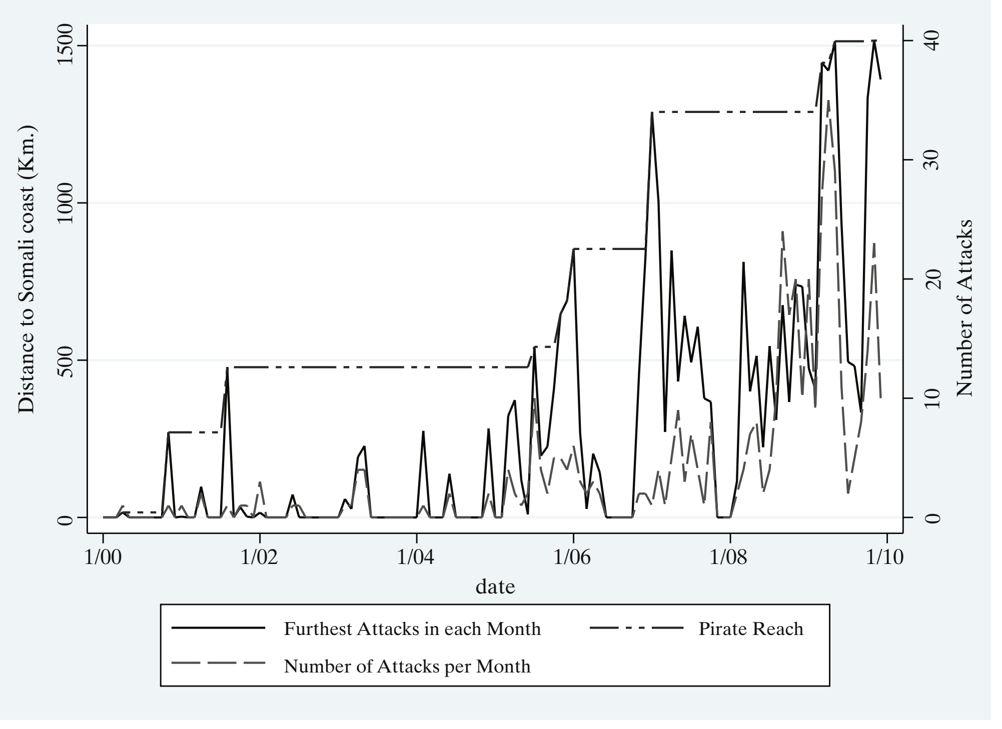

Figure 4. The Maximum Geographic Reach of Somali Pirates

Note: The data display documents the construction and the variation in piracy reach over time. The dashed line corresponds to the monthly number of attacks attributed to Somali pirates (following the assignment described in the Table 2). The continuous line traces the distance (in kilometers) to the furthest offshore point where a pirate attack was reported in a given month. Piracy reach is defined as the largest distance that was ever traveled by pirates *to date*, and is represented in the graph by the long dashed line.

It is important to highlight that one of the main reasons why Somali pirates are responsible for the great majority of hijackings is because they have access to safe havens in Somalia where the hostage ships and crew can be held for a prolonged period of time. In contrast, pirates elsewhere lack such safe havens and must generally limit their activities to theft (Raymond 2009). It is thus no surprise that the costs imposed by pirates outside of Somalia has been found to be relatively small. For instance, Bensassi and Martínez-Zarzoso (2013) find that the only form of pirate activity that affects trade is hijacking, and Besley et al. (2015) find no effect of Indonesian attacks on insurance rates. Because of this, we do not expect to find significant effects of piracy on trade along routes outside the Gulf of Aden and Indian Ocean.

3. Conceptual Framework

In the context of international trade, piracy acts can be thought of as shocks that increase shipping costs. In what follows, we model these shocks as part of the *ad-valorem* (iceberg) trade cost function, and embed this in the standard gravity equation of bilateral trade. The goal is to formalize the direct link between maritime piracy and international trade, which helps us derive the econometric model and the identification strategy.

The Gravity Equation

Following the trade literature, we consider an N-country world with the representative consumer of each country deriving utility from all available products according to a constant elasticity of substitution (CES) utility function. For simplicity of exposition, we disregard the time dimension available in our panel dataset and focus for now on characterizing trade at a given point in time. Standard utility maximization subject to the budget constraint leads to the following aggregate import demand function d_{ij}, in country i for a product traded by country j:

$$d_{ij} = \left(\frac{p_{ij}}{P_i}\right)^{-\sigma} \frac{Y_i}{P_i}, \quad \text{with} \quad P_i = \left[\sum_{j=1}^{N} (p_{ij})^{1-\sigma}\right]^{1/(1-\sigma)} \tag{1}$$

where σ denotes the elasticity of substitution across products, Y_i is the aggregate expenditure in country i (i.e. gross domestic product (GDP)), P_i is the CES price index and represents the aggregate price of the entire consumption bundle, and p_{ij} is the import price paid in country i for a good produced in country j. The import price includes the factory gate price p_j and the *ad-valorem* (iceberg) trade cost τ_{ij}, such that:

$$p_{ij} = \tau_{ij} p_j. \tag{2}$$

Summing the expenditure per product in country i across all the n_j symmetric products traded by the exporting country j results in the following equation for the volume of imports by country i from j:

$$X_{ij} \equiv n_j p_{ij} d_{ij} = n_j Y_i \left(\frac{\tau_{ij} p_j}{P_i}\right)^{1-\sigma}. \tag{3}$$

Following Anderson and Van Wincoop (2003), we can use the goods market clearing condition in the exporting country j (i.e. $Y_j = \sum_{i=1}^{N} X_{ij} = n_j \sum_{i=1}^{N} p_{ij} d_{ij}$), to substitute for the endogenous factory price p_j and for the number of products n_j in equation (3), and get the familiar expression of the gravity equation:

$$X_{ij} = \frac{Y_i Y_j}{Y_W} \left(\frac{\tau_{ij}}{P_i \Pi_j}\right)^{1-\sigma} \tag{4}$$

where $Y_W = \sum_{i=1}^{N} Y_i$ represents the world income. Π_j is a function of all countries' CES price indexes that, under the assumption of symmetric bilateral trade costs, becomes equivalent to the own CES price index P_j.[12]

The log of the gravity equation (4) defines the econometric model that is typically taken to the data in order to estimate the impact of the trade costs τ_{ij} on the volume of bilateral trade:

$$\ln X_{ij} = -\ln Y_W + \ln Y_i + \ln Y_j + (1-\sigma)\tau_{ij} - (1-\sigma)(\ln P_i + \ln \Pi_j). \tag{5}$$

As pointed out by Anderson and Van Wincoop (2003), one empirical challenge in correctly identifying a gravity equation of bilateral trade comes from the fact that the importer and exporter price indexes, known as "multilateral resistance" terms, are unobservable. Since they are a direct function of the bilateral trade costs and of countries' income levels, their omission from the regression model biases the main coefficients of interest. In our specific case, the effect of maritime piracy on bilateral trade is going to be biased if we omit the multilateral resistance terms from the estimation model. Our solution to this problem is to use importer- and exporter-specific fixed effects to account for the multilateral resistance terms. Adding also the time subscripts specific to the panel dimension of our dataset, the preferred gravity equation specification can be written as:

$$\ln X_{ijt} = \alpha_{it} + \alpha_{jt} + (1-\sigma)\ln \tau_{ijt} + \varepsilon_{ijt} \tag{6}$$

where ε_{ijt} represents an error term and accounts for measurement error in the reported trade flows, as well as for any unobserved determinants of bilateral trade.

Piracy and the Trade Cost Function

We model the bilateral trade costs τ_{ijt} as a function of the transportation cost between countries i and j, as well as other implicit frictions known to affect their trade. The bilateral transportation cost is assumed to be determined by the geographic distance between the two trading partners, $Dist_{ij}$, and by the extent of maritime piracy on that trade route at a given point in time, i.e. $PirateRisk_{ijt}$.[13] We denote the other trade frictions by a vector Z_{ij} of bilateral variables, and consider factors such as common language and colonial linkage indicators, as well as participation in bilateral or multilateral trade agreements.[14] In summary, we assume the following bilateral trade cost function:

$$\tau_{ijt} = f(Dist_{ij}, PirateRisk_{ijt}, Z_{ijt}). \tag{7}$$

We measure the risk of piracy in two ways. First, we follow the current literature in using the log of the number of reported pirate attacks in a given year carried out in the proximity of Somalia, $Somali\ Attacks_t$.[15] Unfortunately, this measure is not without problems, as it could severely underestimate the impact of piracy on trade. One reason is reverse causality: the increase in attacks may be partially due to an increase in available targets, something that is quite possible given the significant increase in trade through the gulf of Aden (see Figure 5). Another reason is that shipper's unobserved investments in protection (which increase trade costs) could help reduce the number of recorded attacks.

For these reasons, we also use the variable $Reach_t$, defined as the maximum extent of pirate reach into the sea up until time t. This alternative measure of piracy risk has the advantage of being largely free from these problems. We found no strong reason to suspect that pirates' geographic span of control has to increase at the same rate as the growth of regional trade. In the same way, there is no strong reason to believe that in the absence of changes in aggregate trade—beyond what is predicted by countries' geography and rate of economic growth—the reach of maritime piracy cannot vary over time. Our view is that the geographic expansion of pirate activity is more likely an outcome of the safe haven provided by the position and lawless state of Somalia, the increased availability of technology to pirates, and a slow reaction and coordination of international anti-pirate activities. These conditions provided the suitable environment for the existence and growth of pirate organizations, whose accumulated capital and experience over time allowed them to expand.

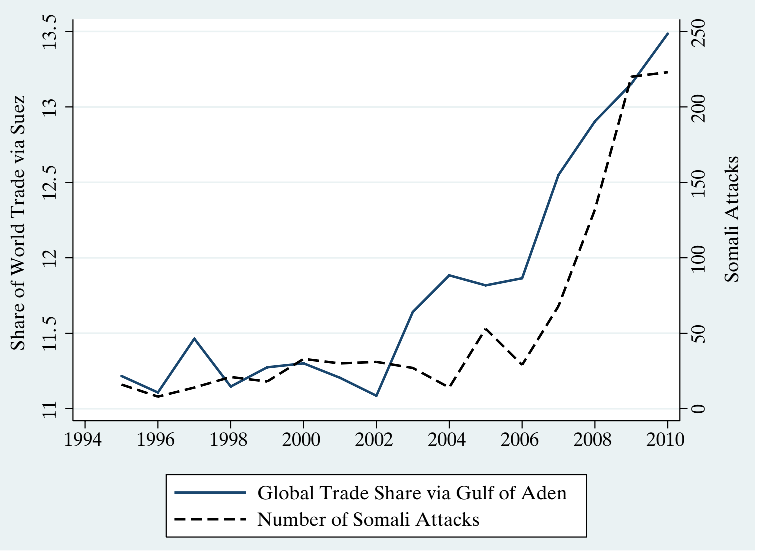

Figure 5. The Importance of the Gulf of Aden as Transit Area for Global Trade

Note: The figure illustrates the fraction of global trade (by value) that is potentially exposed to the risk of maritime piracy over time. This fraction is calculated based on the set of country pairs for which the shortest maritime route goes through the Gulf of Aden and/or the Suez Canal. For comparison, we also plot the number of pirate attacks in that region over time.

In identifying the effect of maritime piracy on transportation costs, we rely on two assumptions. First, we assume that piracy increases shipping costs only if the predicted trade route between countries *i* and *j* goes through pirate waters. Given the incidence of pirate attacks around Somalia, we assume that trade moves through pirate waters if the most likely maritime route (measured by minimum sea distance between a pair of countries) passes through the Gulf of Aden, or through the Indian Ocean. Second, we assume that transport costs along pirate waters are monotonically related to the intensity of pirate activity. At the same time, we allow the responsiveness of trade costs to piracy to differ along maritime routes passing through the Gulf of Aden and the Indian Ocean.

Letting $Aden_{ij}$ be the indicator variable for trade routes through the Gulf of Aden, and letting IO_{ij} be the equivalent for trade routes through the Indian Ocean (see Table 1 for a tabulation of these two variables by country pair), the trade cost function τ_{ijt} for a given time period *t* can be written in log form as:

$$\ln \tau_{ijt} = \alpha_t + \gamma_0 \ln Dist_{ij} + \gamma_1 Aden_{ij} + \gamma_2 Aden_{ij} \times PirateRisk_t + \gamma_3 IO_{ij} + \gamma_4 IO_{ij} \times PirateRisk_t + \delta Z_{ijt} \quad (8)$$

where the time fixed effect α_t captures changes in global trade costs that are common to all country pairs, including changes in the risk of piracy, and the indicator variables Aden_{ij} and IO_{ij} capture the average differences in bilateral trade costs across geographic regions coming from product or partner composition effects.

The *ad-valorem* tax imposed by piracy on trade moving through the Gulf of Aden is given by γ_2, while the tax on trade passing through the Indian Ocean is given by

Table 1. Trade Region Pairs by Route

Route		*Gulf of Aden*	*Malacca*	*Indian Ocean*	*Far East*	*Rest of Africa*
Pirate threat From	*To*	*Somali*	*Malacca*	*Somali Indian Subcont.*	*Far East*	*West and Central African*
East Africa	Europe	1	0	0	0	0
	North America	1	0	0	0	0
	Rest of Africa	1	0	0	0	1
	Indian subcontinent	0	0	1	0	0
	Malacca	0	1	1	0	0
	Far East	0	1	1	1	0
Southern Africa	Europe	0	0	0	0	1
	Rest of Africa	0	0	0	0	1
	Indian subcontinent	0	0	1	0	0
	Malacca	0	1	1	0	0
	Far East	0	1	1	1	0
Rest of Africa	North America	0	0	0	0	1
	Western South America	0	0	0	0	1
	Eastern South America	0	0	0	0	1
	Europe	0	0	0	0	1
	Indian subcontinent	1	0	1	0	1
	Malacca	1	1	1	0	1
	Far East	1	1	1	1	1
Indian Subcontinent	North America	1	0	1	0	0
	Western South America	0	0	1	1	0
	Eastern South America	1	0	1	0	0
	Europe	1	0	1	0	0
	Malacca	0	1	1	0	0
	Far East	0	1	1	1	0
South East Asia	North America	0	1	0	1	0
	Western South America	0	1	0	1	0
	Eastern South America	0	1	0	1	0
	Europe	1	1	1	0	0
	Far East	0	1	0	1	0
Far East	North America	0	0	0	1	0
	Western South America	0	0	0	1	0
	Eastern South America	0	0	0	1	0
	Europe	1	1	1	1	0

Note: The table reports all the worldwide bilateral trade flows included in our estimation sample that are subject to piracy threats in any part of the world. The indicator 1 identifies the routes along which ships are at risk of maritime piracy occurring in the region described by the appropriate column. Many region pairs, including North America to Europe, are not included in this table. Region pairs that are not explicitly listed face no pirate threat along their imputed route.

γ_4. A reason to separately identify the effects of piracy on trade based on the particular maritime route traveled by ships comes from the differences in the incidence of piracy across the two regions. The Gulf of Aden being a narrow passage for ships, all trade transiting through it is subject to piracy. In contrast, as piracy in the Indian Ocean is concentrated in the North West part of the ocean, not all trade shipments crossing the Indian Ocean travel through pirate-infested waters. Thus, the average tax on trade through this area, captured by γ_4, should be smaller than γ_2. Ultimately, our main coefficient of interest is going to be γ_2 because of its unambiguous interpretation.

Substituting the trade cost function into the gravity equation given by equation (6), we get:

$$\begin{aligned}\ln X_{ijt} = \alpha_{it} + \alpha_{jt} + \beta_0 \ln Dist_{ij} + \beta_1 Aden_{ij} + \beta_2 Aden_{ij} \times PirateRisk_t \\ + \beta_3 IO_{ij} + \beta_4 IO_{ij} \times PirateRisk_t + \delta Z_{ijt} + \varepsilon_{ijt},\end{aligned} \quad (9)$$

where the coefficients $\beta_\kappa \equiv (1 - \sigma)\gamma_\kappa$, with $\kappa \in \overline{0,4}$, are reduced form coefficients. Thus, the estimated reduced form effect of piracy on the volume of bilateral trade, given by β_2, combines the effect of piracy on the cost of transport (γ_2), as well as the price elasticity of demand (σ), which also represents the elasticity of substitution among the products in the consumption basket. An implication of this underlying parameter structure is that for a given piracy shock to the cost of shipping goods between two countries, the responsiveness of the volume of imports is larger if the consumers in country i can easily find a substitute for goods produced by country j (i.e. σ is large).

The trade effect of Somali piracy formalized in equation (9) is identified from the differential changes in the volume of bilateral trade across affected vs unaffected trade routes (i.e. difference-in-differences methodology). The regression estimates correctly identify the reduction in trade owing to piracy provided that piracy does not affect country pairs trading outside of pirate waters. A potential concern could arise if exporters increase trade with "safe" partners in response to diminishing trade with "risky" partners, in which case β_2 and γ_2 would capture an upper bound of the trade destruction effect of piracy. However, based on the theory framework, such substitution patterns across trade partners are entirely driven by variation in the multilateral resistance term (i.e. P_i in equation (1)). More specifically, when the bilateral cost of trading with a particular country increases as a result of piracy, the importer price index increases as well, lowering the relative price of imports from other countries. As a result, a larger expenditure share gets allocated to products from lower trade cost, i.e. "safe" partners. Essential to our estimation, this reallocation of expenditures and increase in spending towards low trade cost partners is proportional to the change in the importer price index. So, by controlling for the multilateral resistance terms, we already account for substitution effects across trade partners. This provides another reason why it is important to include importer–year and exporter–year fixed effects in our regression model.

A second issue is that some of the costs associated with Somali piracy and affecting a country's *overall* trade (i.e. bilateral trade with every partner country) are not going to be captured by the coefficient of interest β_2 in the regression equation (9), but rather by the multilateral resistance terms. To illustrate this point, suppose that some countries reduce their expenditure share on all foreign goods because they allocate national resources towards fighting piracy. If the fall is proportional across all trading partners, such a piracy-related trade cost is not reflected in our regression estimate. Rather, the trade reduction is absorbed by the country–year fixed effects. In that sense, our estimates of the impact of Somali piracy on international trade capture a partial equilibrium effect.

In estimating equation (9), it is necessary to account for the fact that trade across different regions grows at different rates for other exogenous reasons, and these growth rates could be spuriously related to trade via the Gulf of Aden. We will address this omitted variable bias problem by showing that our estimate of β_2 is robust to the inclusion of a broad set of importer and exporter controls, including importer–year and exporter–year fixed effects. Finally, we use the

Cameron–Gelbach–Miller procedure to cluster standard errors by importer–year pairs to capture any consumer-specific cyclical component in the error term (Cameron et al. 2011). Alternative error structures do not change the significance of our results.

Tariff Equivalent of Maritime Piracy

If reliable data on bilateral trade costs τ_{ijt} were available for a large set of countries, we would estimate an extended version of the equation (8) to directly find the *ad-valorem* tariff equivalent of maritime piracy, i.e. $\hat{\gamma}_2$. Unfortunately, this approach is not feasible for us since the cost–insurance–freight/free-on-board price ratios that could be calculated from the COMTRADE data and used as proxies for iceberg trade costs are notoriously noisy (Hummels and Lugovskyy 2006). Instead, we exploit the structure of the gravity model together with the estimated coefficients from equation (9) to make inferences about the magnitude of the *ad-valorem* tariff equivalent of maritime piracy. That is, we calculate $\hat{\gamma}_2 = \hat{\beta}_2 / (1 - \hat{\sigma})$ by using estimates from the trade literature for the elasticity of substitution σ.

4. Data

Pirate Risk

The International Maritime Bureau (IMB) via the International Chamber of Commerce (ICC) Commercial Crime Services department collects information on all reported instances of actual and attempted piracy and robbery. This represents the most comprehensive piracy data available for the period 1991–2011. For each reported event, the IMB lists the date, the geographic coordinates, the pirates' suspected country of origin and the outcome from the episode (i.e. attempted boarding, boarding, highjacking, etc.).[16] From these data we construct our two explanatory variables: *Somali Attacks* and *Reach*.

The first measure of piracy, *Somali Attacks*, is calculated by summing up all the attacks initiated by suspected Somali pirates during each year of the sample, regardless of the assailants' nationality on record. Pirates' nationalities are recorded with significant error, with many attacks in the Gulf of Aden being attributed to a number of nationalities. In our main specifications, we considered as "Somali" all pirate activities that took place in the Gulf of Aden or in the North-Western part of the Indian Ocean (refer to Table 2 for the listing of pirate nationalities included in our definition of Somali piracy). However, in one of our robustness exercises we experiment with a more narrowly defined measure of Somali piracy, and show that it has no qualitatively different impact on our estimates.[17]

To construct the second measure of piracy, *Reach*, we use a Geographic Information System (GIS) program to calculate the geographic distance d_{it} between the location of each attack i that took place at time t and the closest point along the Somali coast. We define the geographic reach of pirates as the distance of the furthest attack into the sea up to that time period, i.e. $Reach_t = \max_{s \leq t}\{d_{is}\}$. Since this measure is sensitive to outliers (i.e. isolated events of local piracy across the East African or Arabian peninsula coast), we consider only those attacks attributed to Somalian, Yemeni or Eritrean pirates. As the global positioning system (GPS) coordinates of each attack were not reported by the IMB prior to year 2000, the measure *Reach* is available only from that

Table 2. Assignment of Pirate Attacks to Geographical Areas

Somalia and Indian Ocean (1186 total attacks, 56 per year)	Somalia, Mozambique, Djibuti, Egypt, Eritrea, Kenya, Madagascar, Oman, Tanzania, Yemen
Malacca Strait and South East Asia (2038 total attacks, 97 per year)	Cambodia, Indonesia, Malacca Strait, Malaysia, Myanmar (Burma), Philippines, Singapore Strait, Thailand
West and Central Africa (680 total attacks, 33 per year)	Algeria, Angola, Benin, Cameroon, Congo, Equatorial Guinea, Gabon, Gambia, Ghana, Guinea, Guinea Bissau, Ivory Coast, Liberia, Mauritania, Morocco, Nigeria, Senegal, Sierra Leone, South Africa, Togo, Zaire (DRC)
Far East (441 total attacks, 21 per year)	China/Hong Kong/Macau, East China Sea, Hong Kong/Luzon/Hainan (HLH), Papua New Guinea, Solomon Islands, South China Sea, Taiwan, Vietnam
Indian Subcontinent (689 total attacks, 33 per year)	Bangladesh, India, Sri Lanka
Rest of World (unassigned) (723 total attacks, 34 per year)	Albania, Arabian Gulf, Arabian Sea, Australia, Brazil, Bulgaria, Caribbean, Colombia, Costa Rica, Cuba, Denmark, Dominican Republic, Ecuador, France, Georgia, Greece, Guatemala, Guyana, Haiti, Honduras, Iran, Iraq, Italy, Jamaica, Location not available, Malta, Martinique, Mexico, Netherlands, Nicaragua, Pacific Ocean, Panama, Peru, Portugal, Russia, Salvador, Trinidad and Tobago, Turkey, UAE, UK, Uruguay, USA, Venezuela

year onwards. For consistency, we limit our main data analysis to the sample period 2000–2010 (although we exploit the information on piracy attacks prior to 2000 in one robustness exercise).

It is possible that our two measures of piracy risk suffer from nonclassical measurement error. For instance, it is possible that not all the incidents that actually happened over time were reported by the victimized ships to the IMB. It is also possible that the degree of under-reporting may have changed with sailors' awareness of the Somali piracy problem. To the extent that under-reporting is more of an issue in the early years of the sample, we would overestimate the true increase in piracy over time. This will reduce both the magnitude and precision of the regression coefficients, making our estimates a lower bound. A second potential problem is that, lacking the GPS coordinates of pirate attacks prior to the year 2000, we could underestimate the true geographic reach of pirates in the early part of the sample (if, for example, pirate reach was extensive prior to 2000). However, we believe that this is unlikely to be the case, as anecdotal evidence suggests Somali piracy was limited to the coastal regions throughout the 1990s and early 2000s (World Bank, 2013).

Bilateral Import Volumes

Our bilateral trade data comes from the COMTRADE database provided by the United Nations. It specifies, for all 150 countries in the sample, the total value of imports by product category and source country in a given year. Starting from the Harmonized System (HS) 6-digit level of product differentiation, we construct two measures of bilateral trade: one that captures the total value of trade, aggregated across all traded goods, and one that measures only trade in "bulk" commodities—i.e.

Table 3. Bulk Goods Classification

Description	*HS code 2-digit*	*HS code 6 digit*
Live trees and other plants	06	9
Coffee, tea, spices	09	26
Cereals	10	14
Oil seeds, grains, seeds, medical plants	12	39
Vegetable plaiting materials & products	14	1
Cocoa and cocoa preparations	18	1
Food industry residues & waste	23	2
Tobacco and manufactured tobacco substitutes	24	3
Salt, sulfur, earth & stone lime, cement plaster	25	63
Ores, slag & ash	26	24
Mineral fuels, oils, waxes, bituminous substances	27	8
Fertilizers	31	1
Cotton, including yarn and woven fabric	52	1
Vegetable textile fibers; yarn and woven fabric	53	7
Pearls, stones, precious metals, coins	71	4

Note: The table reports which HS 2-digit categories includes products that are traded as bulk commodities. The classification of products into bulk is available from Cristea et al. (2013) and it is constructed at the HS 6-digit level of disaggregation using information from the GTAP (Global Trade Analysis Project) database. The numbers reported in the third column indicate the number of HS 6-digit products considered to be traded in bulk within each HS 2-digit category.

unprocessed and semi-processed agricultural and mineral goods.[18] Table 3 lists the HS 2-digit sectors and the number of HS 6-digit products within each sector that are considered bulk commodities and are included in our classification. Because of their low value to weight ratio, these goods are more likely to travel by ship rather than air; also, their vessels are easier for pirates to board and attack compared with containerized ships.

Trade Routes and Piracy Exposure

We define trade between countries i and j to be exposed to Somali piracy if the trading route connecting the two locations passes through the Indian Ocean or the Gulf of Aden. Since the COMTRADE database does not include information on maritime routes, these routes were imputed by mapping the shortest sea path linking a trade country pair. We then determined whether the shortest path transits through the Indian Ocean or the Gulf of Aden. Figure 6 indicates how countries were assigned to regions while Table 1 indicates how region pairs were assigned to trade routes with pirate risks.

Control Variables

The trade regressions estimated in this paper follow the gravity model common in the trade literature and, as such, we rely on a standard set of regression control variables. The Centre d'Etudes Prospectives et d'Informations Internationales (CEPII) Gravity

Figure 6. Trade Region Assignments

Note: The shaded trade regions were designed to encompass all countries that would use similar sea routes to trade with countries in another trade region. The countries labeled as *Other* have been dropped from the sample, mainly because of conflicts in assigning a unique trading route.

Dataset provides all the gravity variables that are constant over time.[19] For time-varying variables, this publicly available dataset only goes until year 2006. We use updated values for population and GDP from the International Monetary Fund (IMF) World Economic Outlook Database,[20] and an updated list of trading partners in a Regional Trade Agreement (RTA) or in the General Agreement on Tariffs and Trade/World Trade Organization (GATT/WTO) using information provided by the WTO.[21]

Sample Country Coverage

We restricted the COMTRADE data in the following way. While the data are available from 1991, we restrict attention to the period 2000–2010, which coincides with the beginning and expansion of piracy in the region. Because of ambiguity in determining some of the trade routes, we drop trade involving countries with multiple route profiles, which are the result of countries having ports on multiple seas (e.g. Russia, Saudi Arabia), or being landlocked and without a clear sea trade route (e.g. Kazakhstan). These countries are designated as “other” in Figure 6. We further remove all trade between neighboring countries, as they mostly trade by land. Finally, we drop Somalia from the sample as Somali trade is likely to be endogenous to Somali pirate activity.

Summary Statistics

Panel A of Table 4 reports the average value of bilateral trade, in thousands of US dollars, considered to be routed through the Gulf of Aden, as compared with the rest of world. The annual value of trade between country pairs connected through the Gulf of Aden is, on average, less than half of the value of trade between country pairs that are not linked through that region. Trade in bulk goods makes up a small fraction of the total value of trade, both through the Gulf of Aden and through other routes. That does not mean that bulk trade is unimportant: since bulk trade has low value to weight ratio, it represents a much larger fraction of ship tonnage. For instance, 23% of ships and 16% of tonnage transiting through the Suez Canal in 2009 transported bulk products (Suez Canal Authority, 2013).[22]

Panel B provides summary statistics for some explanatory variables, including the number of attacks and the furthest distance from the Somali coast to an attack. Thirty-two per cent of the country pairs used in the analysis have an imputed trade linkage through the Gulf of Aden. The Suez Canal provides passage to 17% of the total trade and 9.8% of bulk trade in our estimation sample. We use these values to calculate the total trade cost of piracy.

5. Estimation Results

Total Imports

We begin with the analysis of the effects of piracy on the volume of total bilateral imports. Table 5 reports the results from a gravity equation estimated using six different structures of fixed effects. Each specification gradually restricts the amount of data variation used for model identification in order to contain the sources of omitted variable bias. The last specification corresponds to the theory-based regression model in equation (9), while the prior versions provide a useful comparison to existing estimates in the literature.

Table 4. Summary Statistics

Panel A: Bilateral measures

	Gulf of Aden trade		*Other trade*	
	Mean	*SD*	*Mean*	*SD*
Log of total trade ($000s)	7.30	4.02	7.88	4.13
Log of bulk trade ($000s)	5.44	3.33	5.99	3.55
Share of bulk trade in total trade (%)	0.03		0.06	
Average distance (km), total trade	8,434	3,388	6,737	4,354
Average distance (km), bulk trade	8,346	3,085	6,231	4,447

Panel B: Explanatory variables

	Mean	*SD*
Somali Attacks (per year)	82.31	75.42
Log of Somali Attacks (per year)	4.01	0.88
Reach (km)	883.21	449.14
Log of Reach (km)	6.64	0.56
Log of Importer GDP ($bn)	3.92	2.24
Log of Importer Population (million)	2.33	1.88
Log of Importer GDP per Capita ($000s)	1.60	1.57
Aden Route Indicator	0.32	0.47
Share of Total Trade through Gulf of Aden (%)	16.95	1.42
Share of Bulk Trade through Gulf of Aden (%)	9.83	0.54

Notes: All the nominal values—trade volumes, GDP and per-capita GDP—are measured in US dollars. Given the overlap in the set of countries that are exporters and importers, we omit exporter-specific summary statistics. The volume of trade that goes through the Gulf of Aden is determined based on the set of country pairs for which the shortest maritime route transits that region. The categories of products that are classified as bulk are described in Table 1. Sample statistics calculated after dropping observations as described in section 4. *SD* = Standard deviation.

In column (1) of Table 5, we estimate a gravity model that includes only year fixed effects, which controls for cyclical and secular changes in global trade. In the second column we add importer and exporter fixed effects. This specification accounts for time-invariant country-specific characteristics such as geography, industrial specialization, or the average openness to international trade. To better control for idiosyncratic shocks and differential growth rates across countries, column (3) includes importer-specific year dummies, while column (4) adds exporter-specific linear time trends. To account for the fact that the 2008 recession caused a large decline in global trade, with potentially differential consequences across countries, in column (5) we interact a “financial crisis” dummy (set equal to one starting with year 2008) with the exporter-specific linear trend. This specification presumes that the crisis had a different impact across countries, affecting not only their level of exports but also their trend. The most demanding specification is presented in column (6). This represents our preferred specification, as it accounts for the unobserved multilateral resistance terms defined in the theory section. By incorporating both importer–year and exporter–year fixed effects, the estimation controls for

Table 5. Effect of Somali Piracy on Total Bilateral Trade

	Dependent variable: *Log of Bilateral Imports*					
	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
Aden Dummy	0.030	0.319***	0.340***	0.206**	0.202**	0.198**
	[0.118]	[0.102]	[0.090]	[0.093]	[0.094]	[0.096]
Aden × Somali Attacks	–0.054**	–0.070***	–0.075***	–0.042*	–0.041*	–0.040*
	[0.025]	[0.020]	[0.022]	[0.023]	[0.023]	[0.024]
Ind. Ocean Dummy	0.313*	–0.407***	–0.369***	0.133	0.225*	0.294**
	[0.166]	[0.151]	[0.098]	[0.116]	[0.128]	[0.146]
Ind. Ocean × Somali Attacks	0.039	0.126***	0.117***	–0.010	–0.033	–0.050
	[0.037]	[0.031]	[0.023]	[0.028]	[0.031]	[0.035]
Log Population Importer	1.018***	1.117***				
	[0.023]	[0.247]				
Log Per-Capita GDP Importer	1.023***	0.662***				
	[0.035]	[0.075]				
Log Population Exporter	1.181***	–0.561***	–0.600**	–0.060	–0.069	
	[0.016]	[0.209]	[0.233]	[0.624]	[0.766]	
Log Per-Capita GDP Exporter	1.261***	0.459***	0.454***	0.107	0.070	
	[0.019]	[0.042]	[0.051]	[0.080]	[0.100]	
Log Distance	–1.132***	–1.564***	–1.560***	–1.561***	–1.560***	–1.561***
	[0.043]	[0.058]	[0.021]	[0.021]	[0.021]	[0.021]
Common Language	0.877***	0.686***	0.686***	0.686***	0.686***	0.683***
	[0.076]	[0.075]	[0.028]	[0.028]	[0.028]	[0.028]
Colonial Ties	0.884***	1.081***	1.084***	1.083***	1.084***	1.085***
	[0.125]	[0.128]	[0.042]	[0.041]	[0.041]	[0.042]
Common Colonizer (post 1945)	0.702***	0.697***	0.696***	0.695***	0.695***	0.694***
	[0.109]	[0.089]	[0.034]	[0.034]	[0.034]	[0.034]
RTA	0.687***	0.345***	0.372***	0.360***	0.362***	0.365***
	[0.071]	[0.080]	[0.033]	[0.033]	[0.033]	[0.034]
Both WTO	0.416***	0.226***	0.230***	0.128**	0.157***	0.196***
	[0.062]	[0.057]	[0.044]	[0.055]	[0.058]	[0.068]
ACP–EU	–0.078	0.022	0.027	0.006	0.008	0.006
	[0.110]	[0.113]	[0.044]	[0.044]	[0.044]	[0.045]
Fixed Effects Specification:	*Year*	*Importer Exporter Year*	*Imp–Year Exporter*	*Imp–Year Exp × Trend*	*Imp–Year Exp × Trend Exp × Crisis*	*Imp–Year Exp–Year*
Observations	154,781	154,781	154,781	154,781	154,781	154,781
R^2	0.680	0.698	0.699	0.703	0.703	

Note: The reported results correspond to a gravity model of trade specified by equation (9). The estimation sample covers worldwide bilateral trade over the period 2000–2010. The dependent variable represents the total bilateral volume of imports (in logs). The Aden and Indian Ocean dummy variables are equal to 1 whenever the shortest maritime route connecting two trading partners goes through the Gulf of Aden or Indian Ocean, respectively. Somali Attacks are the total number of Somali pirate attacks occurring within the calendar year; for specifics on assignment of attacks to Somali pirates, see Table 2. All other regression variables are standard gravity variables, whose description is provided in the paper. ***$p \leq 0.01$; **$p \leq 0.05$; *$p \leq 0.1$. Standard errors clustered by importer–year in brackets.

year-by-year changes in import and export patterns that are specific to each trading country but common across their bilateral trade partners.

Across all specifications, we are interested in the interaction between the annual Somali pirate attacks and the indicator for trade through the Gulf of Aden. We find a negative estimated coefficient on this interaction term: bilateral trade through the Gulf of Aden falls relative to trade through other routes in the years of high Somali pirate activity. The magnitude of the coefficient decreases as we implement a more exhaustive structure of fixed effects, going from –0.07 (in the estimation that only accounts for time-invariant country-specific characteristics) to –0.04 in the preferred specification reported in column (6). This coefficient change suggests that the importer-specific and the exporter-specific time effects are essential in accounting for unobservable trade determinants, whose omission would otherwise bias the piracy effect downward. The larger estimates in absolute value that we find when using less stringent fixed effect models, such as, for example, the column (2) specification, are consistent with the results found in previous studies (e.g. World Bank 2013; Bensassi and Martínez-Zarzoso 2012).

To quantify the impact of maritime piracy, we use the fact that pirate attacks grew by an average of 48.1% per year from 2000 to 2010. Based on our preferred specification, this implies a $0.481 \times (-0.04) = 0.019$ or 1.9% annual reduction in bilateral imports traveling through the Gulf of Aden as a result of piracy over that period, relative to imports shipped through other routes. This result represents a non-trivial reduction in trade. Using our imputed trade routes, we estimate that between 2000 and 2010 an average of US$1.3 trillion passed through the Gulf of Aden each year. A 1.9% reduction in imports through the Gulf of Aden thus represents lost or diverted trade of approximately US$25 billion annually.[23]

Table 5 also reports coefficients on the interaction between piracy and trade through the Indian Ocean. The estimated coefficients are negative in the more restrictive specifications, suggesting that piracy has a negative impact on trade between countries in the Indian Ocean. However, the results are not statistically significant in our preferred specification.[24] Finally, the gravity control variables are generally significant and have the expected sign. This is true throughout our analysis and, as such, we report only the variables of interest in the remaining tables.

Table 6 reports the results from estimating equation (9) using the alternative measure of maritime piracy—i.e. pirate reach. In the interest of space, and to stay close to the theory-motivated gravity equation specification, we only report the specifications from the last three columns of Table 5. Again, we find strong statistical significance in our variable of interest and, as before, the magnitude of the coefficient of interest decreases as we include more stringent controls and fixed effects, which points to the importance of these controls in preventing one from overstating the impact of piracy. In terms of magnitude, the estimate in column (3) suggests that a 100% increase in pirate reach is associated with an 8.2% decrease in trade through the Gulf of Aden, relative to other routes. Pirate reach increased an average of 21.3% per year from 2000 to 2010. This corresponds to an average 1.7% trade reduction per year, suggesting an estimated loss of trade through the Gulf of Aden of US$22 billion annually over this period. Lastly, focusing on the interaction term between maritime piracy and the Indian Ocean trade indicator, the estimated coefficient remains negative, statistically insignificant, and consistently smaller than the interaction between the Gulf of Aden indicator and piracy.

Table 6. Effect of Somali Piracy on Total Bilateral Trade (Reach Measure)

	Log of Bilateral Imports		
	(1)	*(2)*	*(3)*
Aden	0.640***	0.639***	0.582**
	[0.238]	[0.239]	[0.241]
Aden × Somali Reach	–0.091**	–0.091**	–0.082**
	[0.036]	[0.036]	[0.036]
Ind. Ocean Dummy	0.265	0.253	0.444
	[0.353]	[0.353]	[0.375]
Ind. Ocean × Somali Reach	–0.026	–0.024	–0.053
	[0.053]	[0.053]	[0.056]
Fixed Effects Specification:	*Imp–Year* *Exp × Trend*	*Imp–Year* *Exp × Trend* *Exp × Crisis*	*Imp–Year* *Exp-Year*
Observations	154,781	154,781	154,781
R^2	0.703	0.703	

Note: The reported results correspond to a gravity model of trade specified by equation (9). The estimation sample covers worldwide bilateral trade over the period 2000–2010. The dependent variable represents the total bilateral volume of imports (in logs). The *Aden* and *Indian Ocean* dummy variables are equal to 1 whenever the shortest maritime route connecting two trading partners goes through the Gulf of Aden or Indian Ocean, respectively. The Somali pirate reach is calculated as the furthest distance from the location of a Somali pirate attack to the closest port on the Somali coast. Standard gravity equation variables—i.e. population and per-capita GDP for both trade partners, distance, common language, colonial ties, common colonizer, RTA, both WTO, ACP–EU—are included in all specifications but omitted from the table. ***$p \leq 0.01$; **$p \leq 0.05$; *$p \leq 0.1$. Standard errors clustered by importer–year in brackets.

Imports of Bulk Goods

Next, we assess how Somali piracy has affected trade in bulk commodities, a category of goods that we expect to be most susceptible to pirate attacks. We estimate variants of equation (9) and report the results in Table 7. For conciseness, we only report the three more comprehensive fixed effects specifications corresponding to columns (4)–(6) in Table 5, respectively columns (1)–(3) in Table 6. In displaying the results for bulk trade, the first three columns use the number of pirate attacks as the measure of pirate activity, while the last three columns use the pirate reach measure.

Focusing on the magnitude of the coefficients of interest, we find larger estimated effects of piracy on the imports of bulk commodities relative to total imports. In part this is driven by the larger elasticity of import demand for homogenous goods, such as the bulk commodities, but this is also the result of a higher responsiveness of trade costs to piracy risks, justified by the fact that ships carrying bulk goods are more likely to be boarded and attacked. The estimate from the preferred specification in column (3) of Table 7 implies a 4.1% annual reduction in trade through the Gulf of Aden over the period 2005–2010 as a result of the 48.1% increase in pirate attacks annually in the Gulf of Aden, while column (6) suggests a 3.3% reduction in trade through the Gulf of Aden owing to the 21.3% annual increase in reach.

Table 7. Effect of Somali Piracy on Bulk Trade

	Dependent Variable: *Log of Bulk Imports*					
Piracy measure:	*(1)* *Attacks*	*(2)* *Attacks*	*(3)* *Attacks*	*(4)* *Reach*	*(5)* *Reach*	*(6)* *Reach*
Aden Dummy	0.341***	0.306**	0.284**	1.052***	1.066***	0.965***
	[0.128]	[0.131]	[0.134]	[0.328]	[0.327]	[0.331]
Aden × Piracy Measure	–0.100***	–0.092***	–0.085***	–0.168***	–0.170***	–0.154***
	[0.031]	[0.032]	[0.033]	[0.050]	[0.049]	[0.050]
Ind. Ocean Dummy	–0.425**	–0.289	–0.200	–0.204	–0.202	–0.075
	[0.189]	[0.202]	[0.220]	[0.519]	[0.519]	[0.538]
Ind. Ocean × Piracy Measure	0.031	–0.003	–0.026	–0.015	–0.015	–0.035
	[0.049]	[0.052]	[0.057]	[0.080]	[0.080]	[0.083]
Fixed Effects Specification:	*Imp–Year* *Exp × Trend*	*Imp–Year* *Exp × Trend* *Exp × Crisis*	*Imp–Year* *Exp–Year*	*Imp–Year* *Exp × Trend*	*Imp–Year* *Exp × Trend* *Exp × Crisis*	*Imp–Year* *Exp–Year*
Observations	82,362	82,362	82,362	82,362	82,362	82,362
R^2	0.435	0.437		0.435	0.437	

Note: The reported results correspond to a gravity model of trade specified by equation (9). The estimation sample covers worldwide bilateral trade over the period 2000–2010. The dependent variable represents the bilateral volume of imports of bulk commodities (in logs). Details on the classification of traded goods are provided in Table 1. The Aden and Indian Ocean dummy variables are equal to 1 whenever the shortest maritime route connecting two trading partners goes through the Gulf of Aden or Indian Ocean, respectively. Somali piracy is measured either by the number of attacks in a year, or by pirates' reach (as in Table 6). Standard gravity equation variables—i.e. population and per-capita GDP for both trade partners, distance, common language, colonial ties, common colonizer, RTA, both WTO, ACP–EU—are included in all specifications but omitted from the table. ***$p \leq 0.01$; **$p \leq 0.05$; *$p \leq 0.1$. Standard errors clustered by importer–year in brackets.

Trade Costs

As discussed earlier, we can infer the *ad-valorem* tariff equivalent of maritime piracy from the gravity equation estimates. Focusing on the results for bulk trade reported in column (3) of Table 7, and assuming an elasticity of substitution for bulk commodities of 10, we calculate an *ad-valorem* tariff equivalent of maritime piracy equal to 0.009 (which corresponds to $\hat{\gamma}_2$ in equation (8)).[25] Given an average increase in piracy attacks by 48.1% per year, the implied increase in the iceberg trade cost is 0.45%, on average.

Making the same comparison based on the piracy reach coefficients, the tariff equivalent of maritime piracy derived from the estimates in Table 7, column (6), is 0.017%. At an average annual increase in piracy reach by 21.3%, the estimate implies an increase in the *ad-valorem* trade cost of 0.36% owing to Somali piracy, on average.

The inferred *ad-valorem* tariff equivalent of piracy turns out to be much smaller in magnitude than the existing estimates in the literature, e.g. Besley et al. (2015). However, we think that the range of values that our calculated tariff equivalents fall into are more likely to be representative for a larger group of traded goods.

Robustness

We next explore the robustness of our coefficients of interest to a number of alternative specifications. The results are reported in Table 8. Each reported specification follows the preferred structure of fixed effects, as defined by equation (9) and used in column (6) of Table 5. In the interest of space, and given their overall insignificance in prior estimations, we omit to report the coefficient estimates for the Indian Ocean variables.

So far we have assumed that maritime piracy has a contemporaneous effect on international trade. It may be the case, however, that it takes a significant amount of time for trade to respond to the piracy threat. In addition, as pirate attacks and trade transactions happen throughout the year, it is reasonable to assume that events in December of 2007 have more of an impact on trade in 2008 than in 2007. An alternative specification would thus assume that attacks in a given year affect trade only in the following year, in which case piracy would enter equation (9) with a one year lag.

Panel A displays the results for our key variables of interest when we lag the piracy measure by one year. The results are similar to our estimates using a contemporaneous measure of attacks (reach), but they are smaller in magnitude and less precisely measured. Further lags (e.g. two years, etc.) as used in Bensassi and Martínez-Zarzoso (2012) yielded insignificant results. The significance of both contemporaneous and one year lagged attacks indicates that there is some delay in trade responsiveness but the delay is much less than a full year.

In panel B we account for pirate activity in the Strait of Malacca in order to ensure that our estimates for Somali piracy are not spuriously capturing other effects. Thus, we include a dummy for trade passing through the Strait of Malacca, as well as an interaction term between the Malacca dummy and the number of attacks recorded in Malacca. In panel C, we take this exercise a step further and include all the piracy regions around the world and their associated attack measures. Comparing these panels with the results in Table 5 indicates that our estimates are robust to conditioning on piracy activity in other regions.

In panel D, we report estimates based on a more narrow definition of Somali attacks, which includes only those countries used to create our reach variable. While

Table 8. Robustness Checks

	Log of Total Imports		*Log of Bulk Imports*	
Dependent Var.:	*Aden Dummy*	*Aden × Piracy*	*Aden Dummy*	*Aden × Piracy*
Panel A: One year lags				
Lag Somali Attacks	0.195*	–0.042	0.206	–0.071*
	[0.102]	[0.027]	[0.144]	[0.038]
Lag Reach	0.542**	–0.078**	0.897***	–0.147***
	[0.228]	[0.035]	[0.329]	[0.051]
Panel B: Malacca Attacks Included				
Somali Attacks	0.201**	–0.044*	0.284**	–0.087**
	[0.098]	[0.023]	[0.138]	[0.034]
Reach	0.628**	–0.091**	0.961***	–0.154***
	[0.247]	[0.037]	[0.341]	[0.052]
Panel C: Attacks from All Regions Included				
Somali Attacks	0.202**	–0.044**	0.279**	–0.086**
	[0.098]	[0.024]	[0.142]	[0.035]
Reach	0.625**	–0.090**	0.971***	–0.156***
	[0.247]	[0.037]	[0.349]	[0.053]
Panel D: Attacks from Somalia, Yemen, Eritrea				
Somali Attacks	0.102*	–0.023	0.114	–0.061**
	[0.053]	[0.017]	[0.073]	[0.024]
Panel E: 2005–2010 sample				
Somali Attacks	0.176	–0.032	0.261	–0.075
	[0.176]	[0.038]	[0.256]	[0.055]
Reach	0.719	–0.097	1.064	–0.162
	[0.703]	[0.099]	[1.007]	[0.142]
Panel F: 1991–2010 sample				
Somali Attacks	0.341***	–0.077***	0.474***	–0.132***
	[0.056]	[0.015]	[0.078]	[0.021]
Panel G: Dyadic Fixed Effects				
Somali Attacks		–0.010		–0.080***
		[0.014]		[0.023]
Reach		–0.024		–0.138***
		[0.021]		[0.035]

Note: Each row and pair of columns represents a separate gravity model estimation given by equation (9), including importer–year and exporter–year fixed effects. The dependent variable is the bilateral import volume of all goods (first two columns) or bulk commodities (second two columns). Panel B includes but omits from the table the Malacca route dummy and Malacca × pirate attacks in Malacca. Panel C includes but does not report Malacca route dummy, Malacca × pirate attacks in Malacca, Far East route dummy, Far East × Far East pirate attacks, West Africa route dummy, and West Africa × West Africa attacks. Piracy reach measures for non-Somali piracy could not be calculated, therefore, for the rows dealing with reach in panels B and C, number of pirate attacks is includes for all regions other than Somlia. Panel D redefines Somali attacks to only include attacks attributed to Somalia, Yemen, or Eritrea; reach could not be calculated with these countries included and as such it has not been reported. Attack location information was not available before 2000, thus, reach is not reported for the 1991–2010 sample. Panel G includes importer–exporter fixed effects in addition to importer–year and exporter–year fixed effects. All specifications include controls for Indian Ocean dummy, Indian Ocean × piracy measure, distance, common language, colonial ties, common colonizer, RTA, both WTO, and ACP–EU, which are not reported. ***$p \leq 0.01$; **$p \leq 0.05$; *$p \leq 0.1$. Standard errors clustered by importer–year in brackets.

this measure is in some sense more precise, it may be inaccurate when measuring attacks because pirates' country of origin is based on the judgement of the attacked ship. In the early years of Somali piracy, captains almost always simply chose the closest country as the likely initiator of the attack. As Somali piracy became more well known, there might have been an increase in the likelihood of captains to assume that attacks came from Somalia, regardless of the location of the ship when the attack occurred.

In panel E, we return to our preferred specification and definition of attacks, but limit our sample to the period 2005–2010, years in which Somali pirates were the most active. With the sample size reduction, we lose some precision; however, the results are broadly consistent with the findings from the preferred sample. In panel F, we expand our sample to include all available observations going back to 1991. The estimated effects of the piracy attacks measure become larger and more significant when early years are included.

Finally, in Panel G, we report the estimates from an even more restrictive fixed effects model than the one in equation (9). It includes country-pair fixed effects, along with exporter–year and importer–year fixed effects. The addition of dyadic fixed effects controls for any time-invariant differences in the volume of trade between country pairs. This absorbs any unobserved compositional effects or systematic differences in trade routes across space. Nevertheless, this is achieved at the risk of controlling too much of the data variation, thus increasing the noise to signal ratio.

As observed from the results in Panel G, the coefficient estimates for total imports are now much smaller and become statistically insignificant. However, the estimates for bulk trade remain statistically significant and are only marginally smaller than those from prior specifications. The estimates thus confirm our main results for trade in bulk commodities, whereas they do not conform the findings for total trade. While excessively limiting the data variation exploited for model identification may be a problem, this specification suggests that the results for the total volume of imports should be treated with caution.

In the Online Appendix (see Supporting Information at the end of this paper), we show a number of additional results. We re-estimate the main specifications instrumenting one piracy measure with the other measure and using a Poisson estimation strategy. We also report estimates based on a sample that excludes the post-crisis period. These estimates broadly confirm the results of the paper. Finally, we show that the trade-reducing effects of Somali piracy come from the intensive margin of trade (i.e. adjustments in the volume of trade within a country pair), and not the extensive margin (i.e. the probability of ceasing trade with certain trade partners).

Heterogeneity Analysis

We now explore the underlying heterogeneity of the estimated trade cost of piracy, starting with differences in bilateral distance among country pairs. There are a number of reasons to think that partners trading through the Gulf of Aden and located in close proximity to one another should suffer larger trade losses compared with more distant country pairs. This is because the distance traveled through pirate waters represents a larger fraction of the total route distance. Furthermore, there may be fewer or less cost-effective ocean routes that could be taken as feasible alternatives to transiting via the Gulf of Aden. To study this issue, we estimate equation (9) on the

Table 9. Heterogeneity Analysis for the Estimated Effect of Somali Piracy

	Log of Total Imports		Log of Bulk Imports	
Dependent Var.:	*Aden Dummy*	*Aden × Piracy*	*Aden Dummy*	*Aden × Piracy*
Panel A: Shortest 50% of routes				
Somali Attacks	0.123	–0.070*	0.905***	–0.292***
	[0.155]	[0.039]	[0.276]	[0.070]
Reach	0.718*	–0.132**	2.635***	–0.436***
	[0.384]	[0.058]	[0.698]	[0.107]
Panel B: Longest 50% of routes				
Somali Attacks	–0.086	–0.045	–0.228	0.021
	[0.143]	[0.034]	[0.225]	[0.058]
Reach	0.216	–0.073	–0.333	0.028
	[0.378]	[0.057]	[0.562]	[0.086]
Panel C: At least one partner in poorest 50%				
Somali Attacks	0.163	–0.028	0.493***	–0.100**
	[0.105]	[0.026]	[0.169]	[0.042]
Reach	0.477*	–0.064	1.266***	–0.176***
	[0.261]	[0.039]	[0.423]	[0.064]
Panel D: At least one partner in wealthiest 50%				
Somali Attacks	0.180	–0.035	0.244	–0.103**
	[0.130]	[0.033]	[0.198]	[0.050]
Reach	0.462	–0.064	1.028**	–0.180**
	[0.333]	[0.050]	[0.503]	[0.077]

Note: Each row and pair of columns represents a separate gravity model estimation given by equation (9), including importer–year and exporter–year fixed effects. The dependent variable is the bilateral import volume of all goods (first two columns) or bulk commodities (second two columns). Subsamples in panels A and B are calculated using the sample median distance of 7,117 km, corresponding approximately to the distance between India and Ireland. Rich/Poor classification for Panels C and D are based on gross national product per capita values for year 2001 provided by the World Bank. All specifications include controls for Indian Ocean dummy, Indian Ocean × piracy measure, distance, common language, colonial ties, common colonizer, RTA, both WTO and ACP–EU, which are not reported. ***$p \leq 0.01$; **$p \leq 0.05$; *$p \leq 0.1$. Standard errors clustered by importer–year in brackets.

subsample of country pairs whose bilateral distance is below (above) the median distance. Panels A and B of Table 9 report the results. It becomes clear that the estimated trade costs are mostly driven by shorter rather than longer routes. The coefficient estimate for *Aden × PirateRisk* is twice as large on short routes relative to the corresponding estimate from the preferred specification in Tables 5 and 6, respectively, and it is highly significant. Focusing on bulk trade, the coefficient of interest goes from –0.085 in the full sample to –0.292 in the short routes subsample when using the number of attacks as a measure of piracy, and from –0.154 to –0.436 when using reach as a measure of piracy. In contrast, the coefficients estimated on the subsample of long routes are much smaller and statistically insignificant. Clearly, proximity to pirate waters matters.

We next consider the possibility that the "piracy tax" is unevenly distributed across poorer and richer countries. This could occur if, for instance, pirates target cargo ships transporting goods originating from or destined to developing countries, perhaps because these ships employ fewer defensive measures. An alternative and maybe a more realistic scenario is that pirates do not target particular ships and that transport companies commingle cargo from different countries. In this case, we should not observe heterogeneity in our estimates based on trading partners' income level. In panel C and D, we run regressions on country pairs where at least one partner is below (panel C) or above (panel D) the median level of income observed in our data sample. Our estimates of the effect of piracy on total trade remain negative but lose precision, while the estimates for bulk trade remain consistently negative and significant. More importantly, the estimated coefficients remain very similar across the two panels, suggesting a lack of an income gradient.[26]

Distribution of the Burden of Piracy

A final consideration must be made about the distribution of the trade-related cost burden associated with Somali piracy across countries. Using annual data averaged over the sample period 2000–2010, we have constructed estimates of the annual value of lost trade for all the countries in our database. Table 10 reports the estimates for the most affected countries. Columns (1) and (2) provide country level statistics on the average income and value of trade traveling through the Gulf of Aden, while column (3) shows the share of total trade going through the Gulf of Aden. Column (4) reports the monetary value of the annual loss of trade as a result of piracy, where we use the estimates from Table 5 for the calculation. Column (5) reports the lost trade as a fraction of total trade. The last column computes what fraction of the global cost of piracy is accounted for by a particular country, where the global cost is estimated to average about a US$24.8 billion loss in trade per year. As mentioned, losses are slightly lower if we use the more conservative estimates from the regressions in Table 6; nonetheless, the discussion below is not particularly sensitive to these differences.

Panel A of Table 10 lists the countries with the highest value of imports lost due to Somali piracy as a share of their total imports. Not surprisingly, all but one of the countries in this list are located in the Indian Ocean and trade heavily with Europe or the Mediterranean region. At the upper end of the distribution, as much as two thirds of Mayotte's imports and half of the total imports of Qatar, Eritrea and Kuwait are estimated to go through Aden. Yet, as a fraction of total trade, the impact of piracy remains fairly limited (column 3). No country loses more than 2% of annual imports owing to piracy and only the three most exposed countries lose more than 1%. In addition, since the countries in the list are generally "small" countries, the value of their losses represents only a small fraction of the total cost (column 5).[27] In monetary terms, the losses for the countries in the list range from US$1 million per year to US$230 million per year, except for India and the UAE, who have estimated losses of more than US$1 billion per year.

An alternative way to illustrate how trade losses are distributed across countries is to rank countries by the *absolute* value of imports lost owing to piracy. This is reported in panel B of Table 10. The countries dominating this list have significantly lower shares of trade moving through the Gulf of Aden. However, being large countries, their value of trade makes up a large share of total trade transiting through the Gulf of Aden. Looking at the piracy problem in this way, it is clear that the burden of piracy falls very heavily on one trading block, i.e. the EU. We estimate annual losses approximating US$11 billion, which represent a fully 44% of the global burden of piracy.[28] China, Japan, the UAE and India make up the remaining countries with costs over US$1 billion. Overall, 70% of the global cost of piracy accrue to only five countries and the EU.

Table 10. Distribution of Piracy Burden across Countries

	Country	GDP (US$bn) (1)	Trade via Suez (US$m) (2)	Trade Share via Suez (%) (3)	Annual Loss as in Trade (US$m) (4)	Annual Loss as Share of Trade (%) (5)	Fraction of Global Loss (%) (6)
Panel A: Most affected countries as fraction of total trade lost							
1	Mayotte	–	318	0.65	6	1.25	0.03
2	Qatar	54	6,440	0.53	126	1.03	0.51
3	Eritrea	1	229	0.53	4	1.02	0.02
4	Kuwait	87	7,660	0.49	150	0.95	0.60
5	Iran	190	11,600	0.48	227	0.93	0.92
6	Seychelles	1	223	0.48	4	0.92	0.02
7	Djibouti	1	301	0.47	6	0.91	0.02
8	UAE	287	59,000	0.46	1,157	0.89	4.66
9	Bahrain	15	2,270	0.40	45	0.78	0.18
10	India	884	58,400	0.40	1,145	0.76	4.61
11	Burundi	1	98	0.38	2	0.74	0.01
12	Niger	4	329	0.36	6	0.70	0.03
13	Sudan	30	2,170	0.35	43	0.68	0.17
14	Rwanda	3	196	0.35	4	0.67	0.02
15	Ethiopia	17	1,650	0.34	32	0.66	0.13
Panel B: Most affected countries, in absolute value of lost trade							
1	EU	12,972	557,763	0.04	10,937	0.08	44.01
2	China	2,860	102,000	0.17	2,000	0.33	8.05
3	Japan	4,590	66,600	0.13	1,306	0.26	5.26
4	UAE	287	59,000	0.46	1,157	0.89	4.66
5	India	884	58,400	0.40	1,145	0.76	4.61
6	USA	12,420	44,600	0.03	875	0.06	3.52
7	Korea, Rep.	782	33,500	0.13	657	0.24	2.64
8	Hong Kong	186	30,200	0.10	592	0.20	2.38
9	Singapore	139	29,100	0.15	571	0.29	2.30
10	Australia	740	28,200	0.24	553	0.47	2.23
11	Turkey	466	23,000	0.22	451	0.42	1.81
12	Taiwan	323	18,400	0.14	361	0.26	1.45
13	Malaysia	151	14,900	0.14	292	0.27	1.18
14	Thailand	207	14,400	0.12	282	0.24	1.14
15	Czech Rep.	135	12,200	0.16	239	0.30	0.96

Note: The reported trade shares are constructed based on the estimation dataset, which excludes intra-regional trade and certain trade routes (see Table 1). All nominal values are provided in US dollars. In column (4), the value of trade lost is calculated from the value of total trade going through the Gulf of Aden (column 2) multiplied by the estimated loss of trade, which is 0.019% per year. Column (5) values are calculated as the amount of trade lost per year (column 4) divided by the amount of total trade in the sample. Column (6) values are calculated as the amount of trade lost (column 5) divided by the sum of all trade losses (computed to be equal to US$24.85 billion per year).

Table 10 highlights an important fact about piracy: while the estimated costs are not particularly large on a global scale and represent a very small share of imports for any country in the world, the monetary value of the losses are large and concentrated among a few countries—most prominently, the EU. It is thus unsurprising that the anti-piracy response has been led by countries on this list—the EU and USA (through NATO), India and China.

6. Conclusion

In this paper, we study the extent to which maritime insecurity affects international trade flows by exploiting the dramatic increase in piracy risk around Somalia. Between 2000 and 2010, pirate attacks grew seven-fold around the gulf of Aden and the Somali coast, with increasingly daring highjackings taking place further and further away from Somalia. The paper provides evidence that the escalating maritime insecurity did cause a reduction in trade volumes, suggesting that Somali piracy remains a global problem affecting countries trading through the Suez Canal.

Using a panel data set that combines information on the bilateral volume of imports with information on the frequency and location of pirate attacks, we identify the effect of piracy on trade through a difference-in-differences methodology. Our empirical model compares the trade response to changes in the risk of piracy between countries trading through pirate waters and those trading through non-affected maritime routes. Using two alternative measures of piracy risk—the number of attacks carried out by Somali pirates, and the geographic reach of pirates off the Somali coast—we estimate that piracy in the Gulf of Aden reduces the volume of trade between the affected country pairs by an average of 1.9% per year from 2000 to 2010, with larger, more significant and more robust effects for trade in bulk commodities.

Using our preferred estimates, we calculate that this reduction in trade represents a loss of US$22–25 billion per year. This is a large number in relation to the benefits gained by pirates (estimated by the World Bank (2013) to be about US$50 million per year), and it is somewhat larger than the existing US$18 billion estimate from the World Bank of the trade effects of piracy. Our larger estimates are the result of addressing an important limitation in the existing literature, namely the presence of omitted variable bias, the endogeneity of pirate attacks, the use of more precise measurement of piracy risk, and a slightly different way of measuring costs that takes into account the demand responses to the piracy threat. While these trade costs remain small relative to the total flow of trade, we find that these costs are not evenly distributed, with a handful of countries shouldering a great majority of the costs.

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Notes

1. The debate on the role of multilateral resistance terms has been central in the "border puzzle" literature, which focuses on a time-invariant trade cost. Other gravity variables of interest, such as bilateral distance or common language, are also time invariant. So, it is mainly studies that investigate the impact of trade policies where time-varying trade frictions are the focus. Interestingly, Baier and Bergstrand (2007) find that once accounting for country–year fixed effects the effect of free trade agreements on member countries' trade is five times larger. This bias correction goes in the opposite direction compared with this paper, which goes to illustrate the many channels through which the omitted multilateral resistance terms affect the estimates.
2. A broader literature has looked at a number of other interesting aspects of Somali piracy that inform our model and assumptions. For example, De Groot et al. (2012) analyze ransom negotiations in the Somali context and find that observables such as length of imprisonment, size of boat and nationality of the crew are all significant determinants of ransom value. Similarly, Ambrus et al. (2014) consider ransom negotiations between Spain and the Barbary pirates in the sixteenth and seventeenth centuries and find that people in captivity for longer periods were ransomed more cheaply.
3. Since Bensassi and Martínez-Zarzoso (2012) restrict the data and analysis to bilateral trade flows between Europe and Asia, their analysis relies mostly on the time variation in pirate attacks as a source of model identification. By considering bilateral trade data from regions trading outside of pirate-infested waters, we effectively construct a reference group against which to compare the fluctuations in trade observed along routes impacted by piracy, and reduce omitted variable bias. In addition, it is also worth highlighting that while Bensassi and Martínez-Zarzoso (2012) focused on all sources of maritime piracy, their positive results are driven by pirate hijackings, which are mostly carried out by Somali pirates.
4. While the number of attacks is high by simple count, the larger volume of vessels passing through the Malacca Strait implies that the ships traveling through that region are less likely to be attacked. While precise numbers are difficult to find, Evers and Gerke (2006) estimate that more than 50,000 ships travel through the Malacca Strait each year, with more recent estimates as high as 70,000 ships per year. In contrast, the Suez Canal Authority reports indicate that travel through the Canal peaked in 2008 with 21,415 ships.
5. Recent reports indicate that piracy is on the decline in Somalia (Saul 2013). Many observers believe the ongoing slow down in attacks is due to the presence of navy patrols and enhanced onboard security (World Bank 2013). These methods of pirate repression are quite costly; thus, pirate risk is thought to continue to affect trade even in the absence of a significant number of attacks.
6. A broad literature has assessed both the manner in which pirates in general and Somali pirates in particular operate and the effectiveness of various strategies designed to stop them. While this information is informative for our econometric modeling and the interpretation of our results, it is not the focus of our analysis. Instead we invite readers interested in these issues to see Gilpin (2009), Hastings (2009), Coggins (2010), Psarros et al. (2011), Percy and Shortland (2013) and the World Bank report (2013).
7. Piracy in the Gulf of Aden is very different from the piracy experienced in the Strait of Malacca. The latter usually consists of small groups of pirates boarding ships and taking valuables such as cash, personal property and other small items. These Malacca pirates tend to act like seagoing burglars, using the threat of violence to take what they can carry and make a relatively rapid departure. Cases where pirates maintain control of the ship for an extended period are rare and ransoms are only carried out by the most organized groups (Raymond 2009).
8. The average duration from hijacking to ransom payment was 6 months in 2011 (Bellish 2013).
9. Somali pirates are estimated to earn US$200 million each year in ransom payments (Besley et al., 2015). In 2010 alone, 1,181 people were taken hostage (ICC International Maritime Bureau, 2010) with detention periods lasting up to 1,178 days (World Bank, 2013).

10. Insurance rates reportedly increased 4,000% from 2008 to 2009 (Frump 2009); between 82 and 97 seafarers have died during pirate attacks, in Somali detention, or during rescue operations (World Bank 2013).
11. For a discussion of how ships choose which, if any, defense measures to employ and the resulting changes in the probability of successful pirate attacks given these choices, see McDermott et al. (2014).
12. To be precise: $\Pi_j = \left[\sum_{i=1}^{N} \frac{Y_i}{Y_W} \left(\frac{\tau_{ij}}{P_i} \right)^{1-\sigma} \right]^{1/(1-\sigma)}$. When $\tau_{ij} = \tau_{ji}$, then $\Pi_j = P_j$.
13. For simplicity of exposition, we ignore the fact that successful hijackings destroy traded goods, and focus only on the indirect trade costs; that is, piracy enters in equations (5) and (6) through τ_{ijt} only.
14. Common border is another variable typically included in gravity equations, but given our focus on trade shipments transported by sea, in our sample we exclude bilateral trade flows between countries that share a border as we expect a significant fraction of trade to be shipped by ground. See section 4 for a description of the selected sample.
15. In this paper, a pirate attack refers to any reported incident of piracy and armed robbery against ships, with no distinction between actual and attempted attacks. Such data is collected, tabulated and disseminated by the ICC International Maritime Bureau (IMB).
16. The data also includes the flag of the attacked vessel. Unfortunately, because of the widespread use of "flags of convenience" and the ability of ships to avoid costly regulations by flying a foreign flag, this information is a relatively poor proxy for either the countries involved in the trade or the location of the shipping firm (Hoffmann et al. 2004).
17. We also generated a number of piracy variables associated with other regions of the world: West Africa, the Indian Subcontinent, East Asia, Strait of Malacca, and Rest of World. Table 2 indicates how attacks from different nationalities are assigned to regions.
18. The classification of goods into bulk commodities is available from Cristea et al. (2013), and it is constructed at the HS 6-digit level of disaggregation using information from the GTAP (Global Trade Analysis Project) database.
19. Details about the data construction can be found in Head et al. (2010). The data source is available at: http://www.cepii.fr/CEPII/en/bdd_modele/presentation.asp.
20. http://www.imf.org/external/pubs/ft/weo/2012/01/weodata/index.aspx.
21. List of Regional Trade Agreements: http://rtais.wto.org/UI/PublicAllRTAList.aspx; list of membership into the WTO: http://www.wto.org/english/thewto_e/thewto_e.htm.
22. http://www.suezcanal.gov.eg/TRstat.aspx?reportId=3.
23. In this study, we define the piracy-induced "*loss of trade*" as the reduction in the volume of imports from a particular trade partner, which is caused by the increase in iceberg trade costs as a result of Somali pirate activity. To be specific, if X_{ij} defines the volume of imports of country i from country j traveling through the Gulf of Aden, then an increase in *PirateRisk* between periods 0 and 1 causes a loss of trade given by:

$$LostTrade_{ij} = \hat{\beta}_2 \left(\frac{PirateRisk^1 - PirateRisk^0}{PirateRisk^0} \right) X_{ij}^0$$

where $\hat{\beta}_2$ represents the estimated coefficient on the interaction term $Aden_{ij} \times PirateRisk_t$ in equation (9), and $X^0 = X^1 / (1 + \hat{\beta}_2 (\%\Delta Piracy))$. Our trade loss calculation is similar to Bensassi and Martínez-Zarzoso (2012). It differs from the World Bank (2013) study as the latter calculates the trade-related cost of piracy by applying the *ad-valorem* tariff equivalent of piracy to the volume of trade passing through the Gulf of Aden. The strategy adopted by the World Bank thus does not take into account the demand response from an increase in import prices as a result of piracy, which explains why the study arrives at a smaller estimated cost of piracy.
24. We also ran each specification while including a dummy variable for trade traveling through the Strait of Malacca and an interaction term with the number of attacks there. Generally, the coefficients on these variables are not significant and their inclusion does not affect our other estimated coefficients.

25. To calculate the tariff equivalent of maritime piracy, we divide the gravity equation estimate of –0.085 from column (3) in Table 7 by $1 - \sigma = 1 - 10 = -9$. Note that the values for the elasticity of substitution σ typically assumed in the trade literature range between 5 and 10 for all goods trade (see Anderson and Van Wincoop (2003), among others). Given our focus on more homogenous product categories such as bulk commodities, we have decided to experiment with the upper bound value of σ.
26. Alternative ways of cutting the data, for instance by considering the income of sender only or importer only, lead to similar results.
27. The list excludes a possibly important large country, Saudi Arabia, for which we could not precisely estimate partnerships affected by piracy.
28. Within the EU, the burden for Germany is US$2.5 billion, for the UK it is US$1.7 billion, for France it is US$1.3 billion and for the Netherlands it is US$1.2 billion. Italy, Spain and Belgium have burdens ranging between US$700 million and US$1 billion, with the remaining countries contributing US$300 million or less per year.

Supporting Information

Additional supporting information may be found in the online version of this article at the publisher's web site:

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