The Economic Implications of Disruptions to Maritime Oil Chokepoints

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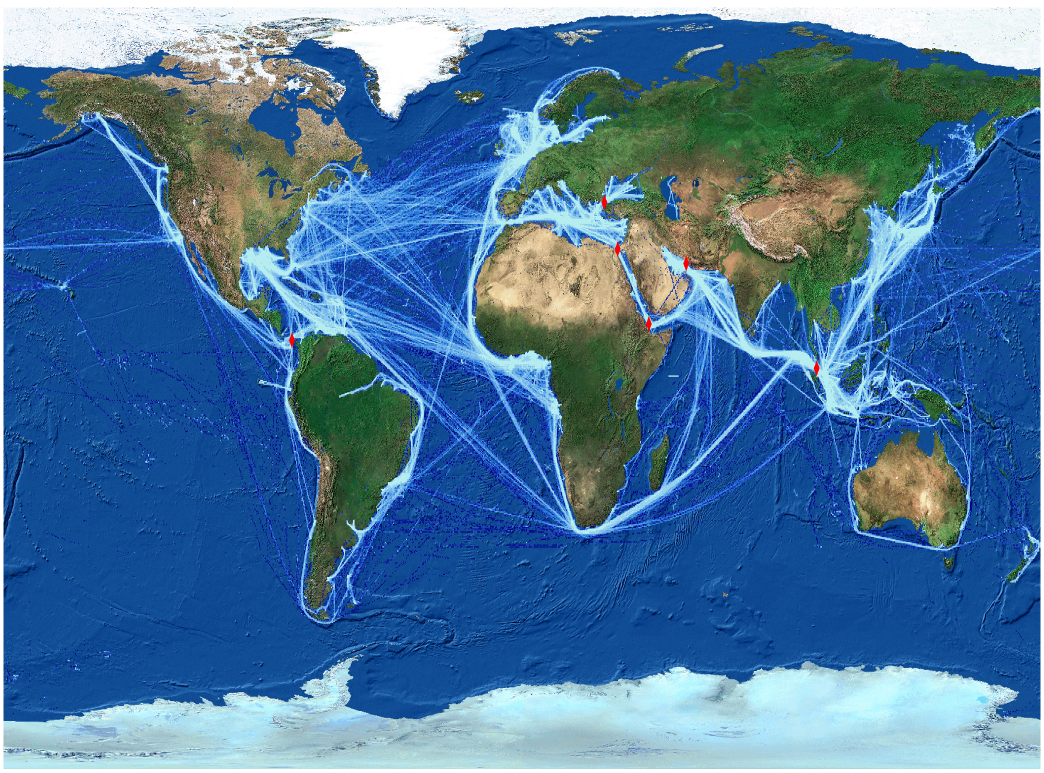

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Executive summary

The free flow of oil is critical to world commerce and global economic prosperity. Oil trade requires the use of maritime trade routes, which can span from hundreds to thousands of miles. Hence, oil tankers often travel through straits and canals to reduce transport costs. These passageways—referred to as chokepoints—are narrow channels along the most widely used global sea routes.

This study evaluates how potential disruptions at critical chokepoints could affect the U.S. economy and economies around the world. While our methods could be used to understand the importance of any chokepoint, we focus on the Strait of Hormuz, the Strait of Malacca, the Suez Canal, the Bab el-Mandeb Strait, the Turkish Straits, and the Panama Canal. At any of these chokepoints, the world's oil supply is at risk of disruption, and the oil transported through these chokepoints has great value. As much as 17 million barrels per day (bbd) flow through the Strait of Hormuz alone. Additionally, chokepoints tend to be in proximity to poor countries, which often lack institutions that can enable or provide maritime security.

Threats to the world's chokepoints are numerous and diverse. The Strait of Hormuz is under a direct threat of closure by Iran. Somali pirates and terrorists are a growing concern for traffic through the Bab el-Mandeb Strait and the Suez Canal. China may become involved in a conflict over the Strait of Malacca as Asia's demand for energy grows, and environmental catastrophes could grow in scale and frequency in the Turkish Straits as tanker traffic increases.

We must be prepared for a disruption to the flow of oil—potentially through a maritime chokepoint. The value of the oil that is at risk is high, and a large disruption is not implausible. One independent 2004 study estimated a 25-percent probability that one substantial disruption would occur before 2014 [1]. (A substantial disruption is one involving 5 million bbd or more—equal to or greater than that experienced after the 1990 Invasion of Kuwait).

If a disruption occurs, countries could mitigate the gross loss to the flow of oil in several ways. Oil could be transported through major pipelines, which have more than 5 million bbd in unused capacity. In some cases, like the Strait of Malacca, oil tankers could travel along alternative trade routes. Certain oil importing countries would have the option to draw down their strategic reserves, and certain oil exporting countries could provide more oil than they otherwise would supply to the market.

We account for potential mitigation in our economic theory of oil supply disruptions. A disruption to the supply of oil transported through a chokepoint is assumed to cause a country's supply of oil to fall by an amount equal to the product of (1) the net number of barrels disrupted and (2) the probability that a barrel is en route to that country given it is transported through that chokepoint. The country's reduced supply of oil would cause the level of total production to decline. Therefore, the country's national, or total, income would fall and its unemployment rate would rise. The oil supply disruption would cause an eventual increase in the price of oil, and the rate of inflation—or growth rate of overall prices—would rise.

Our method for using this theory to estimate the economic impacts of oil supply disruptions is straightforward. We draw on two techniques—Input-Output analysis and Keynesian analysis. These methods are often used by economists to measure the effects of macroeconomic shocks, and our calculations involve only simple algebra. We use data that are publicly available from sources like the Energy Information Agency (EIA) and the CIA World Factbook.

We find that a few of the world's industrialized countries would enter a sudden, steep recession if a major oil disruption occurs at the Strait of Hormuz *and* the countries with large strategic reserves do not share them with the rest of the world. Our findings for the economic impacts of disruptions on the United States are similar to the results of comparable studies. However, where those studies focus solely on the U.S. economy, we examine the effects of oil supply disruptions on over 30 countries for which the required data are available.

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Background and tasking

The secure transportation of oil is critical to world trade and economic growth. Oil trade requires the use of maritime trade routes because two-thirds of the world's oil exports are transported by ocean [4]. Maritime trade routes can span thousands of miles. Hence, oil tankers often travel through straits and canals to reduce the cost of transporting oil. These passageways—referred to as chokepoints—are narrow channels along the most widely used sea routes.

Several chokepoints are critical to the global energy security network because of the high volume of oil that passes through them. The U.S. Energy Information Administration (EIA) remarks that the following waterways are the world's most important oil chokepoints: the Strait of Hormuz, the Strait of Malacca, the Suez Canal, the Bab el-Mandeb Strait, the Turkish Straits, and the Panama Canal [4].[1]

Fortunately, traffic through these chokepoints has rarely been impeded or shutdown. However, political, religious, ethnic, and territorial disputes have made the world anxious in anticipation of obstruction. Furthermore, our dependence on oil continues to grow as our demand and consumption increase. Because the oil imports of the United States, Europe, and Asia are projected to increase, ensuring the flow of oil through maritime chokepoints will continue to be a crucial issue in the years to come.

In this study, we look at how closures of critical chokepoints might affect the U.S. economy and economies worldwide. Specifically, we

1. We are not aware of estimates of the flow of oil through the Strait of Gibraltar. However, a disruption to the Strait of Gibraltar is likely to have similar economic effects on the United States as a disruption to either the Suez Canal or the Bab el-Mandeb.

- Identify which chokepoints vital to global oil transportation are at risk of disruption or closure
- Summarize the ability of countries to mitigate the potential economic impact of an oil supply disruption through alternative strategies, such as the drawdown of strategic reserves
- Develop an approach to quantify the potential economic impact of an oil supply disruption
- Use this approach to quantify the potential economic effects of a disruption for the United States and other countries
- Compare the approach and findings of this study to those of similar studies, where possible

Introduction

This section describes the six chokepoints that are most important to world oil trade. Our key findings are described below:

- Due to the volume of oil that passes through them, the Strait of Hormuz and the Strait of Malacca are by far the most crucial chokepoints to world oil trade. They are, therefore, subject to risk from instability.
- All six oil chokepoints are in close proximity to countries that economists regard as developing, rather than developed.

In this section, we highlight current threats to oil chokepoints. These include the following:

- The Strait of Hormuz is the only chokepoint under a direct threat of closure by a nation within the chokepoint's region.
- Somali pirates and terrorists are a growing concern for traffic through the Bab el-Mandeb Strait—and, in turn, the Suez Canal is also of concern.
- China may become involved in a conflict over the Strait of Malacca as Asia's demand for energy grows.
- As tanker traffic has increased, environmental catastrophes have become a greater concern for the Turkish Straits.

This section also presents evidence that supports the hypothesis that a large disruption of Arabian Gulf oil is likely. Specifically,

- One 2004 study by Stanford University estimated the probability of a substantial (5 million bbd or more) disruption between 2004 and 2014 to be roughly 25 percent [1].

Oil chokepoints

Chokepoints can be described by the countries that border them, the bodies of water that they connect, and the amount of oil traffic that flows within their confines. Table 1 summarizes these characteristics.

Table 1. Six most important oil chokepoints by volume

	Bodies of water	High per capita GDP (2009)	Low per capita GDP (2009)	Oil traffic (2006) million bbd
Strait of Hormuz	Gulf of Oman, Arabian Gulf	UAE: $36,500 (15)[a]	Iran: $11,200 (71)	17
Strait of Malacca	Indian Ocean, Pacific Ocean	Singapore: $50,500 (4)	Indonesia: $4,200 (120)	15
Suez Canal	Mediterranean Sea, Red Sea	N/A	Egypt: $6,100 (101)	4.5
Bab el-Mandeb Strait	Red Sea, Gulf of Aden	Djibouti: $2,500 (135)	Eritrea: $700 (177)	3.3
Turkish Straits	Sea of Marmara, Mediterranean Sea	N/A	Turkey: $12,500 (65)	2.4
Panama Canal	Atlantic Ocean, Pacific Ocean	N/A	Panama: $11,800 (69)	0.5

a. Rank out of 186 countries. The United States ranked sixth with a per capita GDP of $46,300 in 2009 [5].

Strait of Hormuz

The Strait of Hormuz is a waterway between the Gulf of Oman and the Arabian Gulf. Iran is on the north coast, and the United Arab Emirates and Musandam, an exclave of Oman, are on the south coast. As a measure of living standards in the region, the UAE, Oman, and Iran ranked 15, 35, and 71, respectively, out of 186 countries in terms of per capita GDP in 2009. Whereas per capita GDP in the UAE was $36,500, per capita GDP equalled $11,200 in Iran [5].

For a large area of the Arabian Gulf, the Strait of Hormuz is the only sea passage to the open ocean. In 2006, 15 tankers carried 17 million barrels of crude oil through the strait every day [4].

Strait of Malacca

The Strait of Malacca is a narrow stretch of water between the Malay Peninsula and the Indonesian island of Sumatra. As a measure of living standards in the region, Singapore, Malaysia, and Indonesia ranked 4, 59, and 120, respectively, out of 186 countries in terms of GDP per capita in 2009. Whereas per capita GDP in Singapore was $50,500, per capita GDP equalled $4,200 in Indonesia [5].

The strait connects the Indian and Pacific oceans. Malacca is the shortest sea route between Arabian Gulf suppliers and the Asian markets—notably China, Japan, South Korea, and the Pacific Rim. In 2006, 15 million bbd were transported through the strait [4].

Suez Canal

The Suez Canal is an artificial waterway in Egypt, connecting the Mediterranean Sea and the Red Sea. As a measure of living standards in the region, Egypt ranked 101 out of 186 countries in terms of per capita GDP in 2009. Egypt's per capita GDP was $6,100 [5].

The canal enables water transportation between Europe and Asia without navigating around Africa. In 2006, an estimated 3.9 million bbd of oil flowed northbound through the Suez Canal to the Mediterranean, while 0.6 million bbd traveled southbound into the Red Sea [4].

Bab el-Mandeb Strait

The Bab el-Mandeb Strait is located between Djibouti, Yemen, and Eritrea. As a measure of living standards in the region, Djibouti, Yemen, and Eritrea ranked 135, 136, and 177, respectively, out of 186 countries in terms of per capita GDP in 2009. Whereas per capita GDP in Djibouti was $2,500, per capita GDP equalled $700 in Eritrea [5].

The strait is north of Somalia and connects the Red Sea to the Gulf of Aden. In turn, the strait links the Indian Ocean and the Mediterranean Sea via the Red Sea and the Suez Canal. In 2006, an estimated 3.3 million barrels of oil passed through the strait each day [4].

Turkish Straits

The term Turkish Straits refers to two straits in northwestern Turkey that form a boundary between Europe and Asia. With a per capita GDP of $12,500, Turkey ranked 65 out of 186 countries in 2009 [5].

The Bosporus connects the Sea of Marmara with the Black Sea in the north. The Dardanelles connects the Sea of Marmara with the Mediterranean in the southwest. The Turkish Straits supply western and southern Europe with oil from the Caspian Sea region. In 2006, an estimated 2.4 million bbd of oil flowed southbound through this passageway [4].

Panama Canal

The Panama Canal joins the Atlantic and Pacific oceans. With a per capita GDP of $11,800, Panama ranked 69 out of 186 countries in 2009 [5].

The Panama Canal is only marginally relevant to the global oil trade. In 2006, 0.5 million bbd of crude products were transported through the canal [4]. In 2007, the government of Panama began expanding the canal, and this expansion is expected to almost double the current maximum size of ships able to use the canal [4]. However, oil transportation will likely not increase dramatically, as many oil tankers would still be too large [4].

Sources of risk

Threats to the flow of oil are numerous and diverse. In the current maritime security environment, adversaries are likely to focus on the interdiction of commercial shipping in order to degrade the U.S. or world economy [3]. Mines remain the greatest challenge in this environment because they are cheap, numerous, widely proliferated, and capable of constraining maneuverability from deep water to the littoral. Moreover, the forces responsible for sweeping mines are often subject to harassment by area-denial weapons and fires from the shore [3].

Strait of Hormuz

The most serious dispute over the Strait of Hormuz was the "Tanker War" from 1983–1988. In total, Iran attacked 554 oil tankers, which resulted in the deaths of 400 mariners. There was a 25-percent reduction in tanker traffic through the Gulf at the worst point in the fighting. This occurred even though less than 2 percent of ships passing through the Arabian Gulf were disrupted [6].

Tensions between Iran, other Gulf Arab states, and the West have remained high over the past decade [7]. Iran continues to conduct annual military maneuvers and has operated its speedboats in provocative manners [8]. This year, Iran held its military exercises earlier than usual after the country's leaders expressed concerns that the United Stateshad made a veiled nuclear threat against Iran [9]. There is no indication that tensions in this region will subside in the near term.

During the past several years, Iran also has stated that it would respond to a Western attack by closing off the flow of oil through the Strait of Hormuz. Table 2 provides the dates of recent threats by influential Iranians, their positions of influence, and the threat in quotation marks.

Table 2. Threats of state closure to the Strait of Hormuz

Date	Position	Quotation
8 Jul 2008	Clerical aide to the Supreme Leader of Iran	"The Zionist regime is pressuring White House officials to attack Iran. If they commit such a stupidity, Tel Aviv and U.S. shipping in the Persian Gulf will be Iran's first targets and they will be burned" [10].
5 Aug 2008	Commander, IRGC[a]	"Closing the Strait of Hormuz for an unlimited period of time would be very easy" [11].
27 Apr 2010	Secretary-General, ICP[b]	"If America goes lunatic, the children of the nation in the Islamic Republic's armed forces would choke the West's throat at the Strait of Hormuz" [12].
26 Jun 2010	Rear Admiral, IRGC	"At any time, we can exert as much pressure in this Strait as we wish" [13].

a. Iranian Revolutionary Guard Corps
b. Iran's Islamic Coalition Party

Strait of Malacca

Although piracy in the strait has declined in recent years, the number of pirate attacks in the region still ranks highly when compared with the world's other important waterways [14]. While piracy may be a diminished threat, terrorism may be a growing concern as numerous terrorist organizations are present in the region [15]. In March 2010, Singapore's Navy warned that a terrorist group might be planning attacks on oil tankers in the Strait of Malacca [16].

In the Strait of Malacca, maritime traffic will increase significantly as Asia's demand for oil grows [7]. With the increased traffic, there will be more targets for pirates and terrorists. China holds a great interest in this chokepoint, and how they would use their military to respond to a future threat of closure remains to be seen. Chinese President Hu Jintao has stated that China faces a "Malacca Dilemma"—China's oil supply lines are vulnerable to disruption. China is building up military forces and setting up bases along sea lanes from the Middle East in order to project its power overseas and protect its oil shipments. These activities include building naval bases in Burma and electronic intelligence gathering facilities on islands in the Bay of Bengal and near the Strait of Malacca [17].

Suez Canal

The dramatic increase in piracy in the Gulf of Aden could cut off global sea routes through the Suez Canal. There were more than 60 pirate attacks off the Somali coast and in the Gulf of Aden in 2008—more than twice the total for 2007 [18]. Somali pirate attacks grew in number again in 2009. As hull and cargo insurance premiums rose for vessels transiting the Gulf of Aden, some of the vessels that regularly use the Suez Canal chose to go around the Cape of Good Hope rather than enter the Gulf of Aden [19].

Bab el-Mandeb Strait

The attack of the USS *Cole* on 12 October 2000 was a significant act of terrorism in the Gulf of Aden [20]. Since that time, terror organizations have planned several attacks against oil tankers in the Arabian Gulf and in the Horn of Africa. For example, in October 2002, al-

Qaeda attacked a French supertanker off Yemen. As a result of the attack, the insurance premiums charged to tankers passing through Yemeni waters tripled [21].

Just as the USS *Cole* brought attention to terrorism in the Gulf of Aden, the hijacking of the oil tanker, Sirius Star, on 17 November 2008, brought worldwide attention to piracy as a threat to maritime security. Acts of piracy have become more frequent as pirates have regularly used "mother ships" to increase their range. As a result, the old warning to stay at least 50 nautical miles from the coast has been replaced by warnings to stay at least 200 nautical miles away [22].

Turkish Straits

The Turkish Straits are navigationally challenging for large-scale marine transportation. Therefore, Turkey has raised concerns over the possibility of an environmental catastrophe in the straits. Table 3 summarizes some of the recent maritime incidents that have damaged the marine environment of the Turkish Straits. While there has not been a major accident since 1999, there were 186 incidents that negatively impacted the environment in 2007 alone [23].

Table 3. List of maritime incidents in the Turkish Straits[a]

25 Mar 1990	Iraqi tanker M/T Jampur carrying gasoline collided with the Chinese flagged bulk carrier M/V Da Tung Shang at Saryer Point. 2,600 tons of oil spilled from Jampur.
14 Nov 1991	Philippines flagged M/V Madonna Lily collided with the Lebanese flagged livestock carrier M/V Rabunion XVIII at Anadoluhisar Point. 5 people died. 21,000 sheep drowned as the Romanian vessel sunk.
13 Mar 1994	Crude oil carrier M/T Nassia collided with the bulk carrier M/V Shipbroker. 27 people died. 9,000 tons of petroleum spilled and 20,000 tons burned for four days. Traffic in the Strait was suspended for several days.
29 Dec 1999	Russian tanker M/T Volganeft-248 grounded at Florya Point with 4,000 tons of fuel-oil on board. 1,500 tons of oil spilled.
7 Oct 2002	Maltese vessel M/V Gotia stranded at Bebek Point. 22 tons of oil spilled.
10 Nov 2003	Georgian flagged cargo ship GGC Svyatoy Panteleymon ran aground off Anadolufeneri. Around 500 tons of oil spilled.

a. Reproduced from [23].

Panama Canal

At one point, it was thought that China's demand for oil was in conflict with U.S. oil security in the Panama Canal. History has proven this not to be true for current U.S.-China relations. Ports at both ends of the canal are managed by a Hong Kong–based conglomerate, Hutchison Whampoa, with ties to the Chinese government and the Chinese military. However, during the past 8 years, trade through the Panama Canal has proceeded uninterrupted [24].

Likelihood of disruption

For four regions, the Stanford Energy Modeling Forum (EMF) has assessed the likelihood of disruptions of various durations (measured in months) and magnitudes (measured in bbd). The regions are Saudi Arabia, other Arabian Gulf countries, countries west of the Suez Canal, and Russia and the Caspian states.[2] Their approach allows interdependencies to exist between events—like conflict in the Middle East—that could lead to a disruption, thereby providing a richer evaluation of the underlying risks of disruptions. The EMF relied on an expert panel to assess the probability of each event [1].

In the EMF study, the amount of disruption could range from no disruption of supply to a complete disruption of supply. For the period between 2005 and 2014, the EMF has estimated the probabilities of 3- to 6-month disruptions of various magnitudes. Their estimates enable several useful calculations. For example, history's worst oil supply disruption occurred after Iraq's attack on Kuwait. The ensuing sanctions on Iraq deprived global markets of at least 5 million bbd. The EMF estimates that the likelihood of a similar or larger disruption occurring in the Middle East between 2005 and 2014 is about 25 percent.

2. For the Stanford EMF study, other Arabian Gulf countries include Iran, Iraq, Kuwait, Qatar, the UAE, and Oman. Countries west of the Suez Canal include Algeria, Angola, Libya, Mexico, Nigeria, and Venezuela.

Strait of Hormuz

In the past, many U.S. analysts have argued that the U.S. military could easily deal with Iranian conventional military forces, and that Iran could not close the Strait of Hormuz to shipping [6]. However, in a fall 2009 report, the Office of Naval Intelligence (ONI) said that Iran could use its naval forces to cut off shipments through the strait [25]. Iran's recently acquired military arsenal includes the following:

- Aviation
  - — Russian-made Sukhoi fighter jets
- Ballistics
  - — Shahab medium-range ballistic missiles
  - — Chinese-made C-801, C-802, and C-701 anti-ship cruise missiles that can be launched from air, land, or sea
  - — Surface-to-air defensive missiles
- Naval
  - — Torpedo-firing and mine-laying, diesel-electric-powered submarines; other mine-laying vessels
  - — Midget submarines and submersible swimmer delivery vehicles that can carry divers and explosives to targets
  - — Chinese-made Houdong-class fast attack naval craft equipped with these modern anti-ship missiles [26]

However, closure of the Strait of Hormuz might be unwise for Iran. Admiral Mike Mullen, chairman of the Joint Chiefs of Staff, was asked last year about Iranian threats to close the strait. He said, "The analysis that I have seen certainly indicates that they have capabilities which could certainly hazard the Strait of Hormuz." But, he added, "I believe that the ability to sustain that is not there" [25]. As the ONI report states, blocking ships from passing through the 90-mile strait would cause Iran "tremendous economic damage," and Tehran would not, therefore, "undertake a closure lightly. [...]. However, given the importance of the strait, disrupting traffic flow or even threatening to do so may be an effective tool for Iran" [25].

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Risk mitigation

In the event of a disruption, countries could mitigate the net number of barrels lost by transporting some oil through pipelines or along alternative sea routes. Some countries might draw down their strategic reserves, and some producers might increase their supply of oil. Listed by chokepoint, we give the best (measured as bbd of unused capacity for pipelines) available pipelines and alternative routes:

- Strait of Hormuz: 2.5 million through the East-West Pipeline, 0.29 million through the Abqaiq-Yanbu Pipeline, 1.65 million through the Iraq Petroleum Saudi Arabia (IPSA) Pipeline, and 0.5 million through the Tapline
- Strait of Malacca: the Lombok and Makassar Straits
- Suez Canal: 0.8 million through the Sumed Pipeline
- Bab el-Mandeb: 2.5 million through the East-West Pipeline; the rest would be detoured around the Cape of Good Hope
- Turkish Straits: no more than 2.4 million through the Caspian Pipeline Consortium (CPC) Pipeline and the Baku-Tbilisi-Ceyhan (BTC) Pipeline combined
- Panama Canal: 0.8 million through the Trans-Panama Pipeline

Our key findings concerning the institutions that govern the buildup and drawdown of strategic oil reserves are listed below:

- The most notable institution is the International Energy Agency (IEA), an energy forum for 28 industrialized countries.
- IEA member countries hold oil stocks equivalent to at least 90 days of net oil imports.

Estimates suggest that the amount of oil that producers do not currently supply, but could supply at a profit, is limited. For simplicity, we assume this excess capacity would not be used for mitigation.

Alternative routes and pipelines

A disruption at a chokepoint might have a less severe impact on the world oil supply if alternative routes and pipelines with unused capacity are available for oil transit. Our quantitative analysis only considers alternatives that are currently available. Further analysis could factor in the expected mitigation provided by canals and pipelines that are currently being planned or constructed. For existing pipelines, capacity net of oil currently transported—not total capacity—is the relevant quantity for understanding how pipelines can be used to mitigate a disruption.

Strait of Hormuz

Current alternatives

Closure of the Strait of Hormuz would require the use of pipelines at increased transportation costs. Alternatives include the Petroline, also known as the East-West Pipeline, which runs across Saudi Arabia from Abqaiq to the Red Sea. The East-West Pipeline has a capacity to move 5 million bbd [4]. Typically, only 2.5 million bbd flow through the East-West Pipeline [7]. The Abqaiq-Yanbu natural gas liquids pipeline, which runs parallel to the Petroline to the Red Sea, has a 290,000 bbd capacity. Other alternative routes include the deactivated 1.65 million bbd Iraqi Pipeline across Saudi Arabia, and the 0.5 million bbd Tapline to Lebanon. Oil could also be pumped north to Ceyhan in Turkey from Iraq [4]. Among pipelines, 5 million barrels of unused capacity—almost 30 percent of total oil shipments through the strait—are available.

Potential alternatives

The Abu Dhabi Crude Oil Pipeline (ADCOP) is currently under construction by China National Petroleum Corporation (CNPC).The ADCOP pipeline will have a capacity of 1.5 million bbd. Use of this pipeline would reduce the total oil shipments through the Strait of Hormuz by about 9 percent, all else equal. The pipeline is scheduled to begin operating in August 2011. The pipeline will allow the UAE to pump about 60 percent of its crude exports to Fujairah port, thus avoiding the Strait of Hormuz [27].

Strait of Malacca

Current alternatives

If the Strait of Malacca were blocked, ships would reroute around the Indonesian archipelago through the Lombok Strait. Most ships transiting the Lombok Strait also pass through the Makassar Strait. The Lombok Strait is located between the islands of Bali and Lombok, while the Makassar Strait lies between the islands of Borneo and Sulawesi in Indonesia. For supertankers, this route is safer than the Strait of Malacca because it is wider, deeper, and less congested [7].

The Sunda Strait connects the Java Sea to the Indian Ocean. Because the strait is very narrow and shallow at certain points, it is difficult to navigate. The Sunda Strait's strong tidal flows, man-made obstructions, volcano, and tiny islands also contribute to the Lombok Strait's status as the more preferable alternative [7].

Avoiding the territorial waters of Indonesia entirely would be much costlier. If prevented from transiting through the Indonesian Archipelago and the Malacca Straits, an oil tanker headed from the Arabian Gulf to Japan would have to reroute around Australia [28].

Potential alternatives

Malaysian, Indonesian, and Saudi companies signed a contract in 2007 to build a pipeline across the north of Malaysia and southern border of Thailand to reduce 20 percent of tanker traffic through the Strait of Malacca [7]. As of December 2009, construction had not begun [29]. Thailand has also developed several plans to diminish the economic significance of the strait. However, Thai leadership has not supported the project because of its high cost [30].

Suez Canal

Current alternatives

The Suez-Mediterranean, or Sumed, Pipeline is an alternative route for oil between the Red and Mediterranean Seas. The pipeline can transport 3.1 million barrels per day of crude oil. In 2006, nearly all of Saudi Arabia's northbound shipments (approximately 2.3 million bbd of crude) were transported through the Sumed Pipeline [4]. This pipeline's 0.8 million bbd of unused capacity could be used to transport about 18 percent of total oil shipments through the canal.

Closure of the Suez Canal and the Sumed Pipeline would divert tankers around the southern tip of Africa [3, 6, 28].

Bab el-Mandeb Strait

Current alternatives

Oil exports that pass through the Bab el-Mandeb Strait are predominantly northbound. This oil could be transported through the East-West Pipeline to bypass the Bab el-Mandeb Strait. However, the pipeline would not have sufficient capacity to transport all of the oil regularly transited through the strait. The remaining 0.8 million bbd —24 percent of the total oil shipments through the strait—would need to be detoured around the Cape of Good Hope.

Turkish Straits

Current alternatives

The CPC Pipeline connects the Tengiz oil field in Kazakhstan to the Novorossiisk-2 Marine Terminal on Russia's Black Sea coast. Throughput reached 500,000 bbd in 2004 and is planned to reach 1.4 million bbd by 2015 [7].

The BTC Pipeline is used primarily to carry oil from the Azeri-Chirag-Guneshli oil field in the Caspian Sea to the Mediterranean Sea. The pipeline's capacity was expected to reach 1 million barrels per day in 2009 [7]. Among pipelines, at most 2.4 million barrels of unused capacity—or 100 percent of total oil shipments through the straits—are available.

Potential alternatives

Kazakhstan has built a 200,000 bbd oil pipeline from Atasu, Kazakhstan, to Alashankou, China [7]. Several other pipeline projects are in various phases of development. In 2008, construction was expected to begin on the Albania-Macedonia-Bulgaria (AMBO) pipeline, a

750,000 bbd pipeline connecting the Black Sea port of Burgas with the Adriatic port of Vlore. Additionally, Russia has engaged in discussions with Bulgaria and Greece over a 173-mile pipeline [4].

Panama Canal

Current alternatives

The Trans-Panama Pipeline (TPP), with a capacity of 800,000 bbd, is the likeliest alternative to the Panama Canal. The TPP is located outside the former Canal Zone near the Costa Rican border and runs from the port of Charco Azul on the Pacific Coast to the port of Chiriquie Grande, Bocas del Toro, on the Caribbean [4]. If the TPP were not used, then the closure of the Canal would cause vessels to reroute around the tip of South America [4].

Strategic reserves

Robust stockpiles of oil around the globe may help mitigate the economic impact of an oil supply disruption during a short-term disruption. Adding up commercial and government stockpiles, major oil consuming countries control more than 4 billion barrels. Moreover, whereas the world's reserve supply once sat in relatively inaccessible pools, much of it now sits in easily accessible salt caverns and storage tanks [31, 32]. Thus, if no oil flowed through the Strait of Hormuz, the world's strategic reserves potentially could replace every lost barrel for almost 8 months.

However, we know little about when and by how much countries build up and draw down their strategic stocks [31]. This is in part because countries have a great deal of autonomy in setting policies to develop and use their strategic reserves. These decisions consider a number of country-specific factors, like unit stockpile holding costs and maximum reserve capacities [33, 34]. For simplicity, we assume that strategic reserves are not used to limit the size of the net disruption.

International Energy Agency (IEA)

The IEA promises to respond decisively to a major oil disruption. Members have agreed to release stocks, restrain demand, switch to other fuels, increase domestic production, or share available oil, if necessary. To optimize the benefits of the separate capacities of its members, the IEA has elaborated flexible arrangements for coordinated use of stocks and demand restraint [35].

The sharing of reserves would entail a complex decision process. The IEA Directorate of Energy Markets and Security would assess the market impact and the potential need for an IEA coordinated response. Based on this assessment, the IEA Governing Board, which is made up of senior energy officials from member countries, would establish a policy for coordinated action. For example, each member country might provide a share of the total response proportionate to its share of the IEA member countries' total consumption [35].

It is difficult to predict IEA policy because the IEA has only twice coordinated the release of strategic reserves—first in response to the 1991 Gulf War, and later in response to the hurricanes in the Gulf of Mexico in 2005 [35]. The IEA claims that their 2005 decision benefited economies by providing oil in order to relax the incentive for producers to withhold supplies for even greater prices in the future. However, we cannot determine whether the IEA decision was the true cause of market stabilization.

Other collective response agreements

The benefits of collective response plans reach beyond the IEA. Close dialogue and cooperation are maintained with consuming countries that are not member countries of the IEA, and collective actions are taken in coordination with major producing countries [35].

Some countries have acquired additional protection from oil disruptions through separate independent agreements. For instance,

- Japan has negotiated with New Zealand on an emergency oil-sharing program whereby New Zealand would pay the market price plus negotiated fees for the amount of oil previously held for them by Japan [36].
- According to the 1975 Second Sinai withdrawal document signed by the United States and Israel, in an emergency, the

United States is obligated to make oil available for sale to Israel for up to 5 years [37].

Excess capacity

To some extent, the price of oil depends on excess production capacity—that is, oil that is not being drilled now, but could be drilled profitably [38, 39]. Although excess capacity could mitigate the effects of a supply disruption, estimates suggest that excess capacity is limited in the short term. Due to several factors, such as the long length of time required before an oil extraction project can begin, we assume that excess capacity will not be available in time to mitigate the worldwide impact on oil prices.

Proven short-term excess capacity

A study by the EMF finds that significant excess capacity is only available from Saudi Arabia and other Arabian Gulf sources—1.6 million and 0.45 million bbd, respectively [1]. In 2005, the EMF convened a panel of experts who provided estimates on likelihoods of various amounts of excess capacity. The estimates are listed in table 4. We can see from the table that most experts agreed that Saudi Arabia had an excess capacity of 1.5 million bbd. It was the opinion of 5 percent of the panel (1 expert) that Saudi Arabia's excess capacity was 5 million bbd. The lower estimates might be more reasonable because excess capacity is only available to offset disruptions if the internal affairs in that region are stable.

Table 4. Excess capacity amount (million bbd) and likelihood[a]

Saudi Arabia		Other Arabian Gulf	
(million bbd)	(probability)	(million bbd)	(probability)
0	10%	0	70%
1.5	75%	1	20%
3	10%	2	5%
5	5%	3	5%

a. Reproduced from [1].

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Method and data

We focus on disruptions to 20, 50, and 100 percent of the gross oil transported through a chokepoint for as many as 90 consecutive days. For disruptions of this length, pipelines and alternate sea routes are the likeliest forms of mitigation. We use the available carrying capacities of pipelines and alternate sea routes to estimate the sizes of net disruptions.

We want to know how much oil each country loses when a disruption to each chokepoint occurs. To estimate these quantities, we make several assumptions. Some of our key assumptions are listed below:

- The destination of a barrel of oil does not affect the likelihood that the barrel is not transported during a disruption.
- A country's share of its continent's maritime oil imports equals the country's share of its continent's total oil imports.
- The only recipients of oil transported through the chokepoint are those countries that the EIA labels primary recipients.

Next, we want to estimate how these reductions in spending on oil would translate into lower levels of income, higher unemployment rates, and higher rates of inflation. In this section and appendices A and B, we briefly outline the mathematics involved.

For our quantitative analysis, we use publicly available data. For every country in the world, we use a recent estimate—provided by the CIA World Factbook—of the level of annual oil imports. The main ingredient for our Input-Output analysis—IO tables for more than 30 industrialized countries—is available through the Organisation for Economic Co-Operation and Development (OECD). For our Keynesian analysis, we use data from the CIA World Factbook, OECD, and other government sources.

Gross disruption

An oil disruption is characterized by its duration and its magnitude. Magnitude is the proportion of barrels that would normally be transported through a chokepoint but that are not because of the disruption. We discuss disruptions with durations no longer than 1 year—reserving our most in-depth analysis for durations no longer than 90 days.[3] We would want to examine longer disruptions if we were interested in how consumers and businesses would substitute away from purchasing oil. While it would be possible to examine the economic impact of longer disruptions, the analysis would require methods significantly more complex than what we use here, and it would introduce many sources of uncertainty.

We simulate disruptions to the world's six major chokepoints. Based on the amount of oil regularly supplied through each chokepoint, table 5 shows the total amount of oil disrupted (in millions of bbd) when the proportion of barrels disrupted is 20, 50, and 100 percent.

Table 5. Gross disruption (millions of bbd), by chokepoint and percent of daily barrels not transported (2006)[a]

	20% disruption	50% disruption	100% disruption
Strait of Hormuz	3.4	8.5	17
Strait of Malacca	3	7.5	15
Suez Canal	0.9	2.25	4.5
Bab el-Mandeb Strait	0.66	1.65	3.3

3. We provide estimates for more than 90-days for the purpose of descriptive inference on the relative vulnerability of countries to disruptions. If higher oil prices are associated with longer disruptions (ceteris paribus), then we would expect our assumption of fixed prices to be inappropriate for understanding long disruptions.

Table 5. Gross disruption (millions of bbd), by chokepoint and percent of daily barrels not transported (2006)[a]

	20% disruption	50% disruption	100% disruption
Turkish Straits	0.48	1.2	2.4
Panama Canal	0.1	0.25	0.5

a. Estimates of oil transported through each chokepoint are reproduced from the EIA [4].

Mitigation by pipeline and alternative sea routes

During a 90-day disruption, the likeliest form of mitigation for an oil disruption is the use of pipelines and/or alternative sea routes. In an earlier section, for each chokepoint, we have cited the pipelines through which oil could be diverted. Table 6 shows the amount of oil that could be diverted through pipelines in millions of bbd and as a percent of the total oil shipments through a chokepoint.

Table 6. Unused pipeline capacity for mitigating a disruption, millions of barrels per day (2006)[a]

	Strait of Hormuz	Strait of Malacca	Suez Canal	Bab el-Mandeb Strait	Turkish Straits	Panama Canal
Pipelines	5	0	0.8	2.5	2.4	0.8
Percent	29	0	18	76	100	100

a. Information on pipelines reproduced from EIA [4].

Comparing tables 5 and 6 reveals that only disruptions to the Turkish Straits and the Panama Canal could be mitigated by pipelines alone. Whereas pipelines will have an immediate effect on the size of a net disruption, the use of alternative sea routes will not affect the size of a net disruption until several days after the disruption begins. Assuming that tankers are not rerouted right after the disruption, the nation receiving oil that passed through that chokepoint would not observe a decrease in maritime traffic until after the last ship to depart the chokepoint before the disruption began reaches its final destination.

Maritime oil imports by chokepoint and country

We make several assumptions to estimate the number of barrels that a country would lose per day if a maritime oil chokepoint is disrupted. For a given chokepoint, we assume that the only recipients of oil transported through the chokepoint are those countries that are primary recipients.[4] For example, table 7 shows that we assume that countries in Asia, Europe, and North America are the only recipients of oil shipped through the Strait of Hormuz.[5]

Table 7. Primary recipients of oil, by continent and chokepoint[a]

	Strait of Hormuz	Strait of Malacca	Suez Canal	Bab el-Mandeb Strait	Turkish Straits	Panama Canal
Africa						
Asia	X	X				
Australia and Oceania	X	X				
Europe	X		X	X	X	
North America	X		X	X		X
South America						

a. List of primary recipients by chokepoint inferred from EIA [4].

In addition to the basic traffic patterns in table 7, we assume the following:

- Asia and Australia/Oceania import all of their oil by tanker.

4. The EIA has specified for each major chokepoint, the continents (in some cases, countries) that are major recipients of oil [4].
5. We assume that South America and Africa do not receive oil shipped through chokepoints. Those continents produce enough oil to meet their own demands [42, 43]. Hence, we feel that the simplicity gained by the assumption is worthwhile.

- Europe and North America receive equal shares of their supplies by tanker.
- Europe and North America share the oil transported through the Suez Canal and the Bab el-Mandeb Strait equally.
- Europe and North America's respective shares of the Strait of Hormuz are determined by their residual demands for oil.
- Asia and Australia/Oceania share—according to their total maritime imports—the remainder of the oil that passes through the Strait of Hormuz.
- Asia and Australia/Oceania's respective shares of the oil that passes through the Strait of Malacca are determined by their residual demands for oil.

We discuss the remaining assumptions for estimating the number of barrels lost to each country in appendix A. While these assumptions may appear strong, they yield estimates—see table 9—similar to those reported by the EIA.[6]

Effect of oil disruption on total spending

Input-output (IO) analysis is a technique used by economists to estimate the impact of a macroeconomic shock on an economy's spending in the short term. IO analysis was used to estimate the economic impacts of Hurricanes Katrina and Rita. Whereas this study finds that monthly economic losses equalled $384 million, an independent study that used a more complex method estimated losses of $373 million [44]. IO analysis was also used to estimate the economic impacts of the terrorist attacks on 11 September 2001. That study produced estimates that were similar to the results of a more complex project by the Government Accountability Office (GAO). The GAO estimated that the cumulative sustained loss of all metropolitan areas in

6. About 93 percent of Arabian Gulf oil exports travel through the Strait of Hormuz [7], so we can use imports from the Arabian Gulf as a measure of imports from the Strait of Hormuz. Australia/Oceania, Asia, Europe, and North America import roughly 1, 61, 20, and 18 percent of oil exports from the Arabian Gulf [46].

the United States was $191 billion over 5 years. The IO study estimated that this loss was $158 billion over the same time period[45].

We use IO analysis to examine the decline in aggregate spending that would ensue during an oil disruption. We favor IO analysis for three reasons: (1) the basic assumptions and calculations of IO analysis are straightforward relative to many macroeconomic models, (2) IO models have been estimated for a large number of countries, and (3) as we discuss in a later section, IO models provide reasonable estimates of the economic impacts of an oil disruption.

We provide a detailed explanation of our IO analysis in appendix B. In short, our IO analysis estimates how much total spending changes per day in response to oil disruptions. As figure 4 in appendix C illustrates, we use those estimates to calculate the number of days of lost spending that would result in a 1-percent decline in GDP in the medium run. A 1-percent decline in GDP is a good benchmark because it represents a severe, but not unprecedented, decline in living standards.

Effect of oil disruption on income

We use Keynes's expenditure model—figure 4 in appendix C—to examine the decline in aggregate income that would result after an oil disruption. According to this model, as total spending increases with the economy's GDP, higher levels of income result in higher levels of total spending. Thus, a small change in total spending is magnified into a larger change in GDP. This is called the multiplier effect. For a discussion of the mathematics behind the Keynesian expenditure model, see appendix C.

Unemployment

In the medium run, an oil disruption would impact more than a country's income. Unemployment is likely to increase. Okun's law—a rule of thumb—is an empirically observed relationship relating unemployment to losses in a country's GDP. We use Okun's original statement of his law—a 3-percent decrease in GDP corresponds to a 1-percentage-point increase in the unemployment rate.[7]

Inflation and the world price of oil

Okun's law is a rule of thumb for relating changes in GDP to changes in unemployment. There are also rules of thumb for relating changes in oil prices to changes in the overall price level. Because some countries are more sensitive to swings in oil prices, these rules of thumb vary by country [48].

Simple economic models represent an oil disruption as a decrease in the world supply of oil.[8] Of note, the world price of oil during an oil disruption is linked to the net rather than the gross disruption in oil supplies. Net disruptions refer to the amount of oil removed from the market, after accounting for mitigation—say, the use of alternative routes and pipelines.

To estimate the eventual effect of a net disruption on the world price of oil, we assume that for each barrel lost on net, there is a constant response in terms of dollars in the world price.[9] We use the linear response rule suggested by the EMF: Oil prices will rise by $5.26 for each 1 million bbd of net oil disruption.[10] Other often-used methods might exaggerate the price effects of large disruptions [49]. Hence,

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7. Recent estimates suggest that unemployment is slightly more responsive to changes in GDP [47]. This would cause our analysis to underestimate the economic effects of oil supply disruptions.

8. Fewer barrels of crude oil are available for sale at every world price. This assumes away how the supply reduction of crude oil from a particular location might affect the price of other crudes and the average transaction price of all crudes. To reflect the links between markets for various crudes, empirical estimates of the world price of oil weigh specific crude oil prices by the estimated crude oil export volume for each oil-producing country.

9. Economists often rely on estimates of oil price elasticities of supply and demand—that is, the percent change in quantity demanded or supplied for each 1-percent change in oil price. However, there is an important disadvantage in using fixed price elasticities directly to measure the impacts of a large disruption. Fixed elasticities mean that as prices rise, a given unit increase in price will result in increasingly large declines in oil consumption and production. As a result, for large disruptions, fixed elasticities often imply implausible declines in oil trade.

our method provides estimates that would be relatively optimistic from the standpoint of a net oil importer.

Data on oil imports

The CIA World Factbook [43] provides a recent level of oil imports for every country in the world.[11] Table 8 shows our estimates of total oil imports and maritime imports (transported through a chokepoint) by continent. This table is in agreement with the often cited fact that about two-thirds of the 66 million barrels of oil that are imported each day are transported by tanker through a chokepoint [3, 43].

Table 8. Oil imports, by continent[a]

	Africa	Asia	Australia/ Oceania	Europe	North America	South America	Total
Maritime	0	24,519,000	901,000	9,613,000	7,667,000	0	42,700,000
Total	1,717,000	24,519,000	901,000	20,837,000	16,619,000	1,836,000	66,429,000

a. Totals derived from data in [43].

Data for IO tables

The OECD IO database presents IO tables that illustrate flows between sales and purchases (final and intermediate) of industry outputs. The OECD IO tables are produced from many data sources, such as research and development expenditure data, employment statistics, pollution data, and energy consumption. Because the

10. The EMF reports this estimate as their best guess, and they concede that one cannot rule out any price effects in the \$3.50 to \$10.50 range per 1 million barrels per day of net disruption.

11. Oil import figures include both crude and oil products measured in barrels per day. We do not distinguish between crude and oil products in our estimates of '$disruption_{ij}$'. While for different countries the most recent figures can be from different years, we treat all figures as if they were observed in the same year. Among all countries, the most recent estimates are for the years between 2007 and 2009 [43].

OECD used a standard industry list to construct these tables, comparisons can be made across countries. For all but three of 35 countries for which IO tables are available from the OECD, we use the most recent OECD table.[12]

Data on gross domestic product and household consumption

As appendix C explains, the key component of the Keynesian expenditure model is the total spending function. Estimating total spending functions for multiple countries is difficult because of the data requirements involved. Hence, we know of only one study that has done so by regression analysis. While the study provides an estimate of the total spending function for 11 countries, the study is old. It covers the years 1985 to 1996 [51].

We take a simpler approach, and assume that the slope of the total spending function—called the marginal propensity to consume (MPC)—is the same across countries. This will understate (overstate) the impact of a disruption for countries with consumers who are relatively more (less) responsive to changes in income.

We estimate the MPC as an average of each country's MPC between the years 2004 and 2005.[13] We estimate the value of this "universal" MPC to be approximately 0.80. This figure seems reasonable because it is within a few percentage points of the MPC of the United States, Hong Kong, Taiwan, and the Philippines [51].

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12. These tables are meant to describe relationships between industries in the year 2005. We could not use the 2005 tables for Norway, Russia, and Singapore because the OECD was unable to collect data on the oil industries of these countries in 2005. In these cases, we use tables from the year 2000. The tables are available online through the OECD's Structural Analysis (STAN) database. For IO analysis, we need the matrix (*I-R*) discussed in appendix B. The OECD provides the inverse of this matrix, known as the "IO Leontief Inverse Matrix" [50].

13. We use GDP data from the CIA World Factbook [52, 53]. Household final consumption expenditure data were largely from the World Development Indicators database [54]. Tax revenue as a percentage of GDP primarily comes from the OECD and the Heritage Foundation [55, 56]. In some cases, a country's marginal propensity to consume exceeded 1. In those cases, we estimated the country's MPC as 0.99 before calculating the MPC averaged across countries.

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Findings

In this section, we summarize our findings. We begin with our method for estimating the number of barrels transported through each chokepoint en route to each country. Although our method is simple, we show that it provides estimates that are roughly consistent with the few available estimates from the EIA.

Our chief finding is that only a few of the world's industrialized countries would be unable to avoid a sudden, steep recession if a major oil disruption to the Strait of Hormuz occurs, assuming that the few countries with large strategic oil resources do not share them with the rest of the world. For instance, if a 100-percent disruption to the Strait of Hormuz were unmitigated for 90 days, of the 35 countries we examined, three would see their unemployment rate increase by 1 percentage point by the end of the next quarter. If a similar disruption occurred to the Strait of Malacca, one country—Singapore—would suffer this large increase in unemployment. No country would suffer a similar negative economic shock if an unmitigated, complete disruption occurred at any of the other major chokepoints.

Our findings are similar to those reached by comparable studies. The EIA and the Center for Strategic and International Studies (CSIS) found results similar to ours on the effect that an oil disruption in the Strait of Hormuz would have on the GDP of the United States. While our study is limited to explaining the short- and medium-run economic impacts of oil supply disruptions, we are able to estimate those impacts for many more countries than the other studies.

Maritime oil imports by chokepoint and country

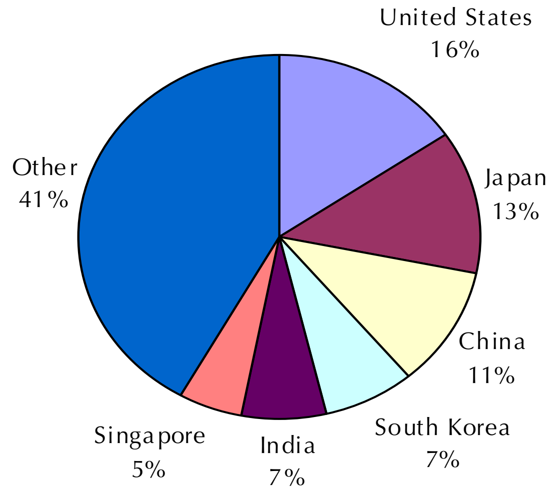
Table 9 shows each continent's share of the oil transported through each chokepoint. The shares for the Strait of Hormuz are quite similar to those estimated by the EIA for 2006 [7].

Table 9. Estimated shares of maritime oil trade, by chokepoint and continent

	Strait of Hormuz	Strait of Malacca	Suez Canal	Bab el-Mandeb Strait	Turkish Straits	Panama Canal
Africa	0	0	0	0	0	0
Asia	0.59	0.96	0	0	0	0
Australia and Oceania	0.02	0.04	0	0	0	0
Europe	0.20	0	0.5	0.5	1	0
North America	0.19	0	0.5	0.5	0	1
South America	0	0	0	0	0	0

For the Strait of Hormuz, figure 1, below, provides the shares for the countries that import the most oil transported through the strait. In the few instances where a comparison is possible, our values are similar to those presented by the EIA [7]. In our economic analysis for the other chokepoints, we use shares that are analogous to those in figure 1. Those shares are presented in table 20 of appendix B.

Figure 1. Shares of oil transported through the Strait of Hormuz



Gross domestic product

The economic losses incurred during an oil disruption depend on the use and sharing of strategic reserves. A country might avoid an economic loss—in terms of forgone GDP—by using oil held as strategic reserves to replace the disruption to its imports.[14] Only a few industrialized countries do not have sufficient strategic oil reserves to replace their oil imports for 90 days. However, it is unclear how many countries would rather maintain their strategic reserves for need in an uncertain future vice deplete their strategic reserves upon the first indication of a disruption. Therefore, we focus on disruptions that are not mitigated with strategic reserves.

First, we report our findings on unmitigated disruptions. Table 10 indicates the duration (in days) of an unmitigated disruption to the

14. It is worth noting that an economic loss would be incurred if the opportunity cost of a barrel of oil held as a strategic reserve is greater than the opportunity cost of a barrel of oil purchased from a producer. This might be true if an oil disruption made it difficult for a country to refill its strategic reserves.

Strait of Hormuz that would result in a 1-percent decrease in GDP the first quarter after the disruption. To emphasize our focus on relatively short disruptions, table 10 is blank where our estimate is larger than 365 days.

Table 10. Durations that would cause GDP to drop by 1 percent in one quarter, Strait of Hormuz

Country	20% disruption	50% disruption	100% disruption
Australia		154	76
Belgium			283
China		171	84
Estonia		179	88
Finland			263
Greece		347	171
Hungary		321	158
India	347	139	67
Indonesia	120	48	23
Israel		318	155
Japan		177	87
Netherlands		233	115
Poland			214
Romania		235	116
Singapore	28	11	6
Slovakia		225	111
Slovenia		312	154
South Korea	143	57	28
Spain			318
Turkey			250
United States			350

We provide estimates larger than 90 days for the purpose of descriptive inference on the relative vulnerability of countries to disruptions. If higher oil prices are associated with longer disruptions (ceteris paribus), then we would expect our assumption of fixed prices to be inappropriate for understanding long disruptions.

By examining table 10, we can see that the world's major economies can be grouped into three categories: the United States and Western

Europe, Eastern Europe, and Asia and Australia. The United States and the countries of Western Europe might be the least sensitive to disruptions of oil supplies through the Strait of Hormuz. Countries in Eastern Europe, like Slovakia, might experience a 1-percent drop in their GDP before countries in Western Europe, like Finland. Finally, countries in Asia are likely to be the most vulnerable to a disruption at the Strait of Hormuz.

Table 11 indicates the duration (in days) of an unmitigated disruption to the Strait of Malacca that would result in a 1-percent decrease in GDP the first quarter after the disruption.

Table 11. Durations that would cause GDP to drop by 1 percent in one quarter, Strait of Malacca

Country	20% disruption	50% disruption	100% disruption
Australia		207	104
China		229	114
Indonesia	160	64	32
Japan		239	119
Singapore	39	15	8
South Korea	192	76	38

As is the case for the Strait of Hormuz, countries in Asia would be hurt most by a disruption to the Strait of Malacca. However, unlike for the Strait of Hormuz, Asian countries and Australia/Oceania are the sole consumers of oil transported through the Strait of Malacca.

Table 12 reports the few remaining instances where an unmitigated 100-percent disruption (shorter than 365 days) could result in a 1-percent decrease in GDP the first quarter after the disruption.

Table 12. Durations that would cause GDP to drop by 1 percent in one quarter, 100-percent disruption

	Suez Canal	Bab el-Mandeb Strait	Turkish Straits
Estonia	164	193	266
Greece	317		
Hungary	293	346	
Netherlands	212	251	345
Slovakia	205	243	334
Slovenia	285	336	

Next, we report our findings for disruptions that are mitigated with pipelines and alternative sea routes. We assume that mitigation starts at the beginning of the disruption. For simplicity, we ignore travel delays caused by the use of alternative sea routes.[15]

Of the disruptions that we examine, only 50-percent and 100-percent disruptions to the Strait of Hormuz could not be entirely mitigated by pipelines and the use of alternative sea routes. Table 13 indicates the duration (in days) of a mitigated disruption to the strait that would result in a 1-percent decrease in GDP the first quarter after the disruption.

Tables 10–13 suggest that among the world's largest economies, Singapore and Indonesia would be the soonest to face severe economic losses due to an oil disruption.[16] The Singaporean economy would be devastated by a disruption's effect on the refining industry. Because of Singapore's location at the crossroads of the Indian and Pacific

15. This decision could imply that we overestimate the number of days of mitigated disruption necessary to result in a 1-percent decrease in GDP. We do not believe that this assumption is of significant consequence. Tables 10–12 suggest that only countries that receive their oil through the Strait of Malacca would suffer severe economic consequences during the period of a reasonable travel delay—say, no more than 24 days. A disruption would have to be unmitigated for at least 1 week to produce severe consequences. Use of the Lombok Strait, as an alternative to the Strait of Malacca, would require an additional 3.5 days at a speed of 14–16 knots [7]. Thus, the only relevant travel delay is so short that travel delays can be effectively ignored.

Table 13. Durations that would cause GDP to drop by 1 percent in one quarter, Strait of Hormuz

Country	50% disruption	100% disruption
Australia		220
China		244
India	353	100
Indonesia	241	68
Israel		228
Japan		253
Singapore	57	16
South Korea	289	81

oceans and its deep-water berths, Singapore has developed some of the largest oil refineries and storage terminals in Asia. The damage to Singapore's petroleum refining would have ripple effects in its growing petrochemical industry.

Unemployment

We estimate that a complete disruption of the Strait of Hormuz mitigated by pipelines would cause Singapore's GDP to ultimately decline by 1 percent if the disruption lasted 16 days. If the disruption lasted 48 days, Singapore's GDP would decline by 3 percent. With a labor force of about 2.99 million people [58], the 1-percentage-point increase in Singapore's unemployment rate would correspond to almost 30,000 newly unemployed workers. Only twice since 1992, has Singapore experienced a larger increase in its unemployment rate [59].

For each disruption that we have considered, table 14 reports the duration (in days) that would result in a 1-percentage-point increase of the unemployment rate the first quarter after the disruption.

16. A 1-percent decline in GDP per quarter would be historically large for Singapore. As a frame of reference, Singapore's GDP fell by 0.5 percent per quarter during the recent global economic downturn of 2010 [57].

Table 14. Durations that would cause the unemployment rate to increase by 1 percentage point

	20% disruption	50% disruption	100% disruption
	Strait of Hormuz (unmitigated)		
Australia			228
China			252
Estonia			264
India			201
Indonesia	360	144	69
Japan			251
Romania			348
Singapore	84	33	18
Slovakia			333
South Korea		171	84
	Strait of Malacca (unmitigated)		
Australia			312
China			342
Indonesia		192	96
Japan			357
Singapore	117	45	24
South Korea		228	114
	Strait of Hormuz (mitigated)		
India			300
Indonesia			204
Singapore		171	48
South Korea			243

Inflation and the world price of oil

Figure 2 shows the increase in the price of oil (measured in dollars per barrel) that we estimate will occur after a disruption if the disruption is not mitigated either by pipeline or by alternative sea route. The estimates vary according to the chokepoint disrupted and the percentage of a normal day's oil trade that is not transported.[17]

17. The increases are relative to an initial price of $77.67. This estimate of the initial price is the average daily world price of oil between July 2009 and July 2010 [41].

Figure 2. Increases to the world oil price if unmitigated, by chokepoint and percent disrupted

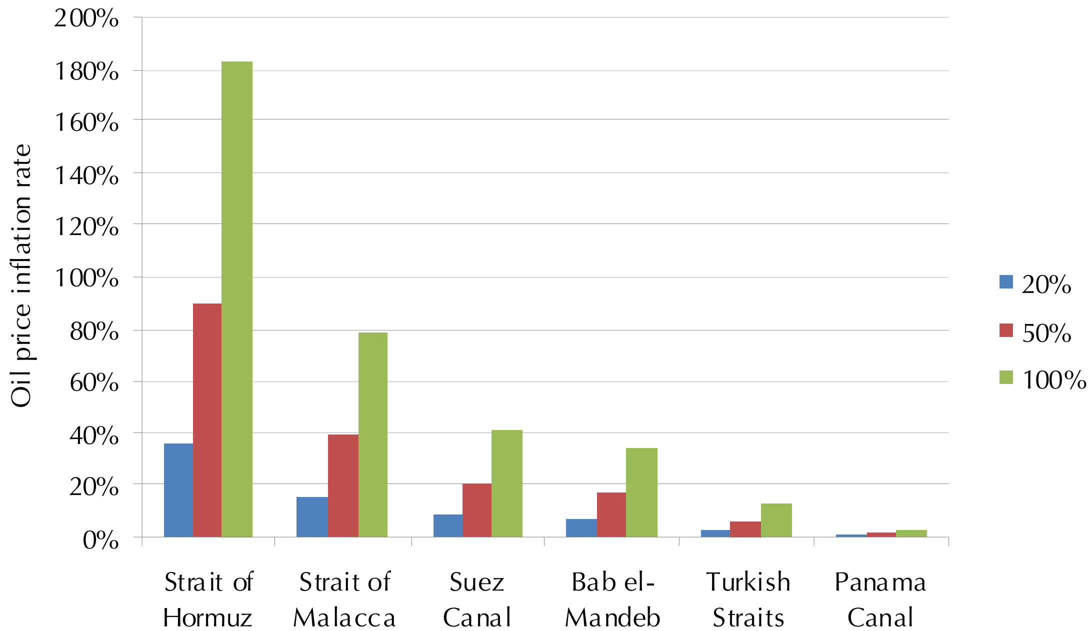
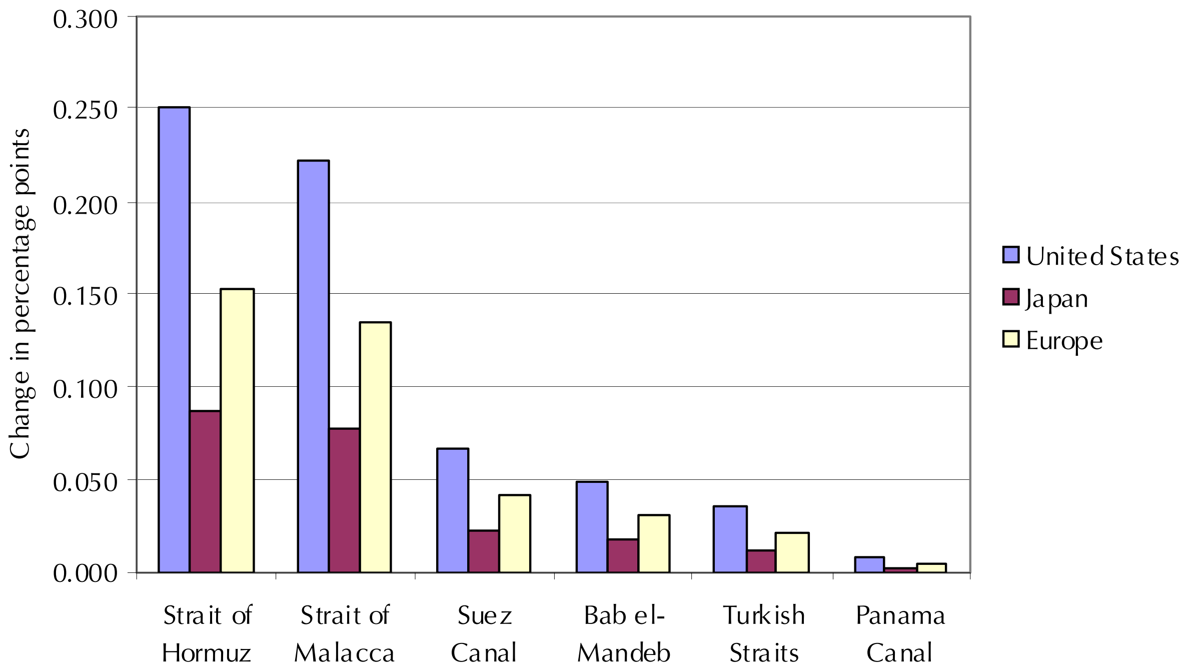


Figure 3 shows the effects that unmitigated disruptions would have on the aggregate price level in the United States, Europe, and Japan. The figure shows percentage-point increases to the quarterly inflation rate as a result of unmitigated 50-percent disruptions. For instance, if 50 percent of the oil that typically flows through the Strait of Hormuz is not transported, then prices in the United States would be about 0.25 percent higher than they otherwise would have been. To put this in perspective, the most the quarterly inflation rate of the United States has ever grown since 1914 is 0.069 percentage points, which occurred between June and September of 1946 [60].

Empirical validation: GDP

Where comparisons are possible, we see that our findings on how an oil disruption would affect GDP are similar to those presented in other studies.

Figure 3. Inflation growth of United States, Japan, and Europe in response to unmitigated 50-percent disruptions



In 2002, a study by CSIS concluded that a 3 million bbd net disruption of the Strait of Hormuz for 90 days, would result in a quarterly GDP growth of rate of -0.89 percent [61]. In 2002, the GDP of the United States was about $10 trillion, so CSIS would have predicted a loss of $8.9 billion. Our analysis would have predicted a loss of about $5.6 billion.

Similarly, the EIA found that a complete disruption to the Strait of Hormuz lasting 30 days would cause GDP per quarter to decline between $11.25 billion and $14.75 billion [62]. Our analysis predicts a loss of $10.6 billion. If the disruption were partially mitigated by pipelines, EIA predicts that GDP per quarter would decline between $4.5 billion and $6 billion. Our analysis predicts a loss of $6.8 billion.

Other observations related to further research

This section recommends areas for research on the protection of maritime chokepoints. Some questions should include the following:

- Stability of oil exporting countries
  - — How might the disruption of an oil chokepoint affect the economy of an oil exporting country?
  - — What security concerns might arise?
- Additional oil chokepoints and vulnerabilities
  - — What other waterways and potential man-made structures are vital to the world oil trade?
  - — How should the Navy address these vulnerabilities?
- Other commercial shipping
  - — How might the disruption of a chokepoint affect non-oil commercial shipping?
  - — What security concerns might arise?
- Cyberspace
  - — Where are the vulnerabilities in the web of undersea cables that are crucial for international communications?
  - — What might be the economic and security consequences of a disruption to these submarine communication cables?

Stability of oil exporting countries

Here, we briefly comment on the effects of an oil supply disruption on oil exporting countries. We focus on Iran and Venezuela because their foreign policies have been in opposition to the United States. We speculate on the relationship between (1) the scale of oil exports in the government revenues of these countries, (2) the activities their governments have funded with their oil revenues, and (3) the effect that an oil disruption might have on their oil revenues—and, thus their activities.

The ability of Iran and Venezuela to pursue policies contrary to U.S. interests depends, in part, on the value of their oil exports. Oil export revenues accounted for 70 percent of Iran's total budget revenues in 2007 [67]. The Venezuelan government relied on revenues from oil for 53 percent of its revenues in 2006 [68]. If budget revenues were lower, either because of lower prices or smaller export volumes, the ability of the Iranian and Venezuelan governments to oppose U.S. interests might be impaired. For example, Iran might have less oil revenue to weather international sanctions meant to slow or stop its uranium-enrichment activities. Likewise, Venezuela might be less able to expand its influence in Latin America and the Caribbean.

A disruption to the supply of oil from the Arabian Gulf might have different effects on the oil revenues of Iran and Venezuela. Although such a disruption might benefit their revenues by causing the world oil price to increase, the quantity of oil exported by Iran might decrease while the quantity of oil exported by Venezuela might increase or remain unchanged. Economists have found that Arabian Gulf oil supply disruptions have a negative effect on the net oil exports and net non-oil exports of OPEC's Middle Eastern member countries, like Iran. These disruptions also have increased the indebtedness of these countries by decreasing the value of their assets owned abroad relative to the value of their domestic assets owned by foreigners [69].

Venezuela—a non-Arabian Gulf member of OPEC—has benefited from disruptions of Middle Eastern oil supplies. Venezuela's GDP and oil revenues are positively correlated with oil-supply shocks driven by OPEC political events [70].

While the disruption of Middle Eastern oil may impede Iran's policy initiatives, it is likely to bolster the initiatives of Venezuela. Because the United States consumes so much Venezuelan oil, the United States may find it difficult to oppose Venezuela. In fact, the United States is the biggest consumer of Venezuelan oil, purchasing 64 percent of Venezuela's total exports of oil in 2007 [68]. Furthermore, substituting away from Venezuelan oil could be prohibitively expensive. Transport costs are much lower to U.S. markets from Venezuela than from other major oil exporters, excluding Canada. And, many refineries in the United States have been specifically built to handle Venezuelan crude oil [68].

Additional chokepoints and vulnerabilities

The free flow of oil depends on the security of several bodies of water, in addition to the six chokepoints that we have examined. For instance, a CNA study in 2008 characterized the South China Sea (SCS) as a critical chokepoint—along with the Strait of Hormuz and the Strait of Malacca—because of its importance to oil and non-oil commerce [71]. Furthermore, the security of the SCS is uncertain. Oil exploration could result in crowding due to a greater number of ships and offshore rigs in the region. There has been a history of violence over territorial claims to the SCS.

Independent of the 2008 CNA study, we have identified the waters off of western India and Sri Lanka as a critical chokepoint in the world's maritime oil trade. Commercial oil tanker traffic data obtained by CNA from the Navy Sealink database show a high concentration of traffic near the western coasts of India and Sri Lanka—see the cover of this report.[18] Certain locations in this region, such as ports and refineries, could be in jeopardy of a sea-based attack.

We recommend that ports be thought of as chokepoints because they are fixed locations and a large amount of oil is transported within their confines. The Coast Guard has examined port security in a large number of countries. According to their metrics, the countries listed in table 16 do not maintain effective port security. We have already discussed the importance of Indonesia to the security of the Strait of Malacca and the importance of Iran to the Strait of Hormuz. Cameroon, Equatorial Guinea, Liberia, and São Tomé & Príncipe border the Gulf of Guinea. Because two major oil exporters—Nigeria and Angola—border this gulf, the Gulf of Guinea should be considered a crucial oil chokepoint. The 2008 CNA study argues the same point.

Table 15. Countries labeled by the Coast Guard as not maintaining effective port security measures[a]

Cameroon	Cuba	Equatorial Guinea	Guinea Bissau	Indonesia
Iran	Liberia	Mauritania	São Tomé & Príncipe	Syria

a. Reproduced from [23].

The world's supply of oil has at least two more sets of vulnerabilities. Recently, 20 to 25 oil supertankers, representing 50 million barrels of oil storage capacity were hired for floating storage [72]. The storage vessels are in the Gulf of Mexico, the North Sea, India, and Malaysia. The use of floating storage, in order to capture higher returns in the future, will likely become more common if (1) technologies increase the available supply of oil to the world market, (2) the world demand for oil declines, or (3) rates for storing oil on tankers fall. The degree to which floating storage is vulnerable to terrorist attack is unknown.

Finally, a disruption to a large oil refinery could have a significant economic impact on multiple countries. The daily refining capacity of each of the world's largest oil refineries exceeds the daily oil traffic

18. The data used to depict commercial oil tanker traffic were obtained from Sealink, a classified Navy/Coast Guard database available via the SIPRNet. Each record includes an individual ship identifier, date and time (to the minute), latitude (to the geographical minute), and longitude (to the geographical minute). We use 0.25-degree boxes (i.e., 0.25 degree latitude by 0.25 degree longitude) to represent the position of a commercial oil tanker. We shade each box to represent the intensity of oil tanker traffic (measured by ship-hours per square nautical mile); bright white indicates a high-traffic region.

through the Panama Canal. Table 17 shows the location and refining capacity of the world's ten largest refineries, as well as the body of water that borders the refinery. Two of these refineries are located near some of the major chokepoints that we have discussed. The Jurong Island Refinery in Singapore borders the Singapore Strait where the Strait of Malacca opens into East Asia. The Ras Tanura Refinery is located in the Arabian Gulf.

Table 16. World's largest oil refineries[a]

Name	Location	Capacity	Body of water
Jamnagar Refinery and Reliance Refinery	Jamnagar, India	1,240,000	Arab Sea
Paraguana Refining Complex	Amuay and Cardon, Venezuela	940,000	Gulf of Venezuela and Lake Maracaibo
SK Energy Ulsan Refinery	South Korea	840,000	Sea of Japan
Yeosu Refinery	South Korea	700,000	Bay of Suncheon
Jurong Island Refinery	Singapore	605,000	Indian Ocean
Baytown Refinery	Baytown, TX, USA	572,500	Gulf of Mexico
Ras Tanura Refinery	Eastern Province, Saudi Arabia	525,000	Arabian Gulf
S-Oil Ulsan Refinery	South Korea	520,000	Sea of Japan
ExxonMobil	Baton Rouge, LA, USA	503,000	Mississippi River
Hovensa LLC	Virgin Islands	495,000	Caribbean Sea

a. Reproduced from [73].

Other commercial shipping

This report shows that the disruption of the world oil trade could have severe economic consequences for some of the world's largest economies. However, 90 percent of world trade is transported by ocean, and oil is not the only commodity that is transported over long maritime trade routes. By ignoring the effect that hostilities at a maritime chokepoint would have on the flow of non-oil commodities, we understate the effect that a disruption to a chokepoint would have on the world economy. Further research could apply methods similar to ours to estimate the economic impact of a disruption to non-oil commodities.

That research, like our study, would fair best to assume away the effects of travel delays on fuel prices. First, the travel delays would likely not be responsible for an increase in fuel prices of more than a few dollars. As a result of a disruption to a maritime chokepoint, the largest cost that oil tanker companies would bear would be an increase in their insurance premiums. The most expensive increase would be the requirement to purchase war risk insurance to cover any intentional damage to hull, cargo, or persons. War risk premiums can reach as high as 10 percent of the market value of the vessel [83]. However, because an oil tanker's cargo has such a high value, the cost of increased insurance premiums could be amortized at less than a couple of dollars per barrel of oil [83].

In addition to shipping insurance, oil tanker companies incur several smaller costs. Those costs are dwarfed by war insurance premiums. Fuel is the largest component of a ship's costs that are unrelated to insurance [83]. In 2004, the average cost of fuel for a VLCC was $14,400 per day [84]. In today's dollars, the daily cost of fuel could be as much as $25,500. This is based on an estimate of daily fuel usage equal to 56.7 tonnes [85] and a current price of bunker fuel equal to $450/tonne [86].

Both estimates suggest the cost of fuel to travel along the preferred alternative routes of the world's maritime oil chokepoints would be easily amortized over the value of an oil tanker's cargo. A typical tanker's cargo is valued at roughly $150 million (2 million barrels at $175 per barrel). Traveling around the southern tip of Africa rather than through the Suez Canal would add an additional 6,000 n. mi. to the tanker route from the Middle East to western Europe. A tanker would travel this distance in about 17 days [4]—adding about $400,000 in fuel costs. If additional fuel costs were entirely passed on to the consumer, then oil prices would rise about 0.3 percent (400,000/150,000,000).

Cyberspace

Submarine communication cables lay beneath the sea and provide telecommunications between countries. As of 2006, undersea cables accounted for nearly 99 percent of international communications traffic, while the remainder was carried by overseas satellite links [87]. These cables are highly valued by national governments. For instance, the Australian government considers its submarine cable systems to be "vital to the national economy." The government of Australia has created protection zones that restrict activities that could damage cables linking Australia to the rest of the world [88].

The reliability of submarine cables is high because multiple paths are available in the event of a cable break. However, the use of submarine cables has not been without incident. For instance, in March 2007, pirates stole an 6.8 mile section of the T-V-H submarine cable that connected Thailand, Vietnam, and Hong Kong. This affected Vietnam's Internet users with far slower speeds [89].

In an era of cyberwarfare, the United States will need to protect the vulnerabilities of the undersea cable system used not only by the United States but also our partners. To support Navy strategy, analysis, and decision-making, we need to determine where vulnerabilities exist. We should also determine how a disruption of submarine communication cables will impact the world's economies.

Conclusion

CNA was asked to evaluate the potential impacts on the U.S. economy from disruptions of critical chokepoints. We find that a few industrialized countries—not including the U.S.—would enter a sudden, steep recession if a major oil disruption occurs *and* the countries with large strategic reserves do not share them with the rest of the world.

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Appendix A

We want to know how much oil a country loses, '*disruption*$_{ij}$', when a net disruption to a chokepoint, '*disruption*$_j$', occurs—for all countries i and chokepoints j.[19] We assume that the destination of a barrel of oil does not affect the likelihood that the barrel is transported during a disruption. Hence, '*disruption*$_{ij}$' is the product of '*disruption*$_j$' and the proportion of barrels traded through chokepoint j, '*trade*$_j$', that are traded to country i,'*trade*$_{ij}$'.

$$disruption_{ij} = \frac{trade_{ij}}{trade_j} \times disruption_j$$

We have already estimated '*disruption*$_j$' for all j in table 5 on page 26, but the trade ratio cannot be estimated so easily. The following observation is useful for estimating the trade ratio.

$$\frac{trade_{ij}}{trade_j} = \frac{continent_{ij}}{trade_j} \times \frac{trade_{ij}}{continent_{ij}}$$

19. '*disruption*$_{ij}$' refers to oil that is being transported on a given day. Oil that flows through the Suez Canal, the Bab el-Mandeb Strait, and to some extent, the Strait of Malacca has originally flowed through the Strait of Hormuz. A similar relationship exists between the Suez Canal and the Bab el-Mandeb Strait. We account for this when we estimate the economic impact of disruptions to these four chokepoints. For example, we assume that a disruption of X percent of the oil from the Strait of Hormuz results in an X-percent disruption to the oil through the Suez Canal, the Bab el-Mandeb Strait, and two-thirds of the Strait of Malacca's oil. The value for the Strait of Malacca seems appropriate because East Asia imports roughly two-thirds of its oil from the Persian Gulf [7].

where '$continent_{ij}$' is the amount of oil transported through chokepoint j to the continent that country i belongs to.[20]

We make several assumptions to estimate '$disruption_{ij}$' in barrels per day. Foremost, we assume that a country's share of its continent's maritime oil imports (the rightmost term above) equals the country's share of its continent's total oil imports.[21] The necessary assumptions to estimate the ratio of a continent's oil imported through the chokepoint relative to the total volume of oil transported through the chokepoint (the middle term above) are presented in the body of this report.

The body of this report also discusses the other assumptions that are necessary to estimate the amount of oil each country would lose if a chokepoint is disrupted. For each chokepoint, table 20 presents our estimates of the ratio of a country's oil imported through the chokepoint relative to the total volume of oil transported through the chokepoint.

Table 17. Shares of oil transported through major chokepoints

	Strait of Hormuz	Strait of Malacca	Suez Canal	Bab el-Mandeb Strait	Turkish Straits	Panama Canal
Argentina	0.000	0.000	0.000	0.000	0.000	0.000
Australia	0.017	0.027	0.000	0.000	0.000	0.000
Austria	0.002	0.000	0.006	0.006	0.013	0.000
Belgium	0.010	0.000	0.026	0.026	0.052	0.000
Brazil	0.000	0.000	0.000	0.000	0.000	0.000
Canada	0.013	0.000	0.035	0.035	0.000	0.070
Chile	0.000	0.000	0.000	0.000	0.000	0.000
China	0.106	0.173	0.000	0.000	0.000	0.000
Czech Republic	0.002	0.000	0.005	0.005	0.010	0.000

20. While '$trade_j$' is known, '$trade_{ij}$' is not. Direct estimation of '$trade_{ij}$' is an infeasible approach because we rarely observe—in the data—the amount of oil an importing country receives from an exporting country.

21. A country's share of its continent's total oil imports can be inferred from publicly available data. However, the assumption is tenuous for those countries that—relative to other countries on their continent—import more or less oil transported by ship.

Table 17. Shares of oil transported through major chokepoints (continued)

	Strait of Hormuz	Strait of Malacca	Suez Canal	Bab el-Mandeb Strait	Turkish Straits	Panama Canal
Denmark	0.001	0.000	0.003	0.003	0.007	0.000
Estonia	0.000	0.000	0.001	0.001	0.001	0.000
Finland	0.003	0.000	0.008	0.008	0.016	0.000
France	0.022	0.000	0.056	0.056	0.113	0.000
Germany	0.026	0.000	0.067	0.067	0.133	0.000
Greece	0.005	0.000	0.013	0.013	0.027	0.000
Hungary	0.002	0.000	0.005	0.005	0.009	0.000
India	0.070	0.114	0.000	0.000	0.000	0.000
Indonesia	0.016	0.026	0.000	0.000	0.000	0.000
Ireland	0.002	0.000	0.005	0.005	0.009	0.000
Israel	0.008	0.013	0.000	0.000	0.000	0.000
Italy	0.021	0.000	0.053	0.053	0.106	0.000
Japan	0.127	0.207	0.000	0.000	0.000	0.000
Luxembourg	0.001	0.000	0.001	0.001	0.003	0.000
Mexico	0.006	0.000	0.014	0.014	0.000	0.029
Netherlands	0.025	0.000	0.064	0.064	0.129	0.000
New Zealand	0.004	0.006	0.000	0.000	0.000	0.000
Norway	0.001	0.000	0.003	0.003	0.005	0.000
Poland	0.006	0.000	0.014	0.014	0.029	0.000
Portugal	0.003	0.000	0.008	0.008	0.017	0.000
Romania	0.002	0.000	0.005	0.005	0.010	0.000
Russia	0.000	0.000	0.001	0.001	0.002	0.000
Singapore	0.051	0.083	0.000	0.000	0.000	0.000
Slovakia	0.001	0.000	0.004	0.004	0.007	0.000
Slovenia	0.001	0.000	0.001	0.001	0.003	0.000
South Africa	0.000	0.000	0.000	0.000	0.000	0.000
South Korea	0.072	0.117	0.000	0.000	0.000	0.000
Spain	0.017	0.000	0.044	0.044	0.087	0.000
Sweden	0.005	0.000	0.013	0.013	0.026	0.000
Switzerland	0.002	0.000	0.006	0.006	0.012	0.000
Turkey	0.005	0.000	0.013	0.013	0.027	0.000
United Kingdom	0.015	0.000	0.040	0.040	0.079	0.000
United States	0.156	0.000	0.405	0.405	0.000	0.811
Vietnam	0.003	0.005	0.000	0.000	0.000	0.000

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Appendix B

An Input-Output (IO) model of a country's economy divides the economy into sectors. Each sector produces goods or services. A production vector *'x'*, lists the output (measured in dollars) of each sector. Each element of '*x*' is the amount spent on primary, intermediate, and final goods produced by a sector. A final demand vector *'d'* lists the values of the goods and services demanded from the productive sectors by the demand sector. Each element of *'d'* is the amount spent on final goods and services from a sector.

As the productive sectors produce the goods specified by the final demand vector, they make intermediate demands for the products of each productive sector. These intermediate demands are described by the production-technology matrix.

The production-technology matrix is constructed from an IO table. This table lists the value of the goods produced by each sector and how much of that output is used by each sector. For example, table 21 is an IO table for an economy with three productive sectors—A, B, and C. Reading the table is straightforward. For instance, sector A spent 'x_{BA}' dollars on inputs from sector B. The sum total of inputs supplied by sector A—$x_{AA}+x_{AB}+x_{AC}$—and final demand for sector A's products—'d_A'—equals the total output of sector A, 'x_A'.

Table 18. Example of an IO table

Productive sector	Inputs to A	Inputs to B	Inputs to C	Final demand	Total output
A	x_{AA}	x_{AB}	x_{AC}	d_A	x_A
B	x_{BA}	x_{BB}	x_{BC}	d_B	x_B
C	x_{CA}	x_{CB}	x_{CC}	d_C	x_C

To create the production-technology matrix, divide each column of the 3×3 table of inputs by the total output for that sector. The result is table 22, the economy's production-technology matrix, 'R'. The parameter, 'r_{BA}', is the share of sector A's total output that is used as inputs by sector B.

Table 19. Example of a production-technology matrix

Productive sector	Inputs to A	Inputs to B	Inputs to C
A	$r_{AA} = x_{AA}/x_A$	$r_{AB} = x_{AB}/x_B$	$r_{AC} = x_{AC}/x_C$
B	$r_{BA} = x_{BA}/x_A$	$r_{BB} = x_{BB}/x_B$	$r_{BC} = x_{BC}/x_C$
C	$r_{CA} = x_{CA}/x_A$	$r_{CB} = x_{CB}/x_B$	$r_{CC} = x_{CC}/x_C$

The equilibrium levels of spending for each sector can now be calculated. These equilibrium levels are the demand levels that will just be met by the intermediate demands of the productive sectors and the final production of each sector. If 'd' is the equilibrium final demand vector, then 'd' must satisfy

$$x = Rx + d$$

Where 'I' is the identity matrix, this equation can be solved for d' to find that

$$d = (I - R)x$$

We model an oil disruption as a reduction in the value of inputs used by a country's oil sector. Therefore, we are interested in knowing how spending on final goods and services, as measured by 'd', changes in response to the change in 'x' caused by the oil disruption.

We make two assumptions. First, the values of 'R' remain constant during an oil disruption. This is plausible because production technologies are unlikely to change in the short run, say the first 90 days of a disruption. Under this assumption, if we let 'Δd' and 'Δx' be the differences in the final demand and total output vectors between the beginning and the end of the disruption, then

$$\Delta d = (I - R)\Delta x$$

We also assume that the total output—the sum of primary, intermediate, and final outputs—of each sector other than oil does not change during the disruption. For, a three-sector economy, if C is the economy's oil sector, then for an oil disruption:[22]

$$\Delta x = \begin{bmatrix} 0 \\ 0 \\ \Delta x_C \end{bmatrix}$$

The extent to which this assumption is plausible depends on the ability to substitute away from oil toward outputs from other sectors to be used as inputs for production rather than to consume those outputs. For a real economy with inflexible production technologies and binding resource constraints, this is a strong assumption and IO analysis provides optimistic estimates.

In this analysis, we are more interested in the change to the overall level of spending on final goods and services than the change to the spending on final goods from a specific industry. Given our assump-

22. Although we would expect the world price of oil to increase during a disruption, the change in total spending on goods from the oil industry is measured holding the world price of oil at its pre-disruption level. We do this because a limitation of input-output analysis is that the proportion of inputs used in an industry's production process does not change regardless of the level of production. A large oil disruption would likely cause price increases so large that industries would change the proportion of oil used in their productive processes.

tions, for the same three-sector economy as above, the change to total final spending caused by an oil disruption is

$$\Delta S = \sum_{j = \{A, B, C\}} \Delta d_j = \sum_{j = \{A, B, C\}} (I - R)_j \Delta x_C$$

Where *(I-R)*$_j$ denotes a row of the matrix *(I-R)*. The first equality is true by definition. The change in total spending is equal to the sum of the sector-specific changes to final spending. The second equality holds because, for a given sector, the reduction in spending on final goods equals the product of the sector's share of total spending on goods produced by the oil sector and the forgone spending on goods from the oil sector. This is true because we assume that the disruption causes a reduction in spending on primary goods, like crude oil.

Appendix C

An objective estimation of how an event, like an oil supply disruption, will affect a country's economy often begins with a macroeconomic model. Such a model assumes that a country earns income by transforming its inputs into its outputs. For our analysis, the key input is oil—more specifically, oil that is transported through a chokepoint.

In this section, we model how the quantity of oil exchanged in the world market translates into the quantity of oil received by each country. Because we assume that the price of oil is fixed during the disruption, we can estimate how much a country's spending on oil declines, using our estimate of how many fewer barrels the country receives.

We use Input-Output analysis in order to estimate how much total spending in a country will decline as a result of the decline in spending on oil. IO analysis uses a matrix representation of an economy in order to predict the effect of changes in spending in one industry on the entire economy. We use Keynesian analysis to estimate how much the reduction in total spending will translate into a reduction of total income. We expect that income will decrease by more than the initial drop in spending because that drop in spending leads to further declines in spending and so results in an even greater decrease in total income.

We use a common rule of thumb to relate the changes in total income to changes in unemployment rates. Similarly, we use simple, empirically valid rules to relate the size of the disruption, the price that oil trades at after the disruption, and the overall level of prices. Finally, we connect the effects of an oil disruption on GDP, unemployment, and inflation through a simple model of the macroeconomy.

Economic theory of oil disruptions

A simple understanding of the economics of oil disruptions begins with the effect of a disruption on a country's spending on oil. How a country's spending on oil will change depends on how a disruption will affect the number of barrels the country imports and the price per barrel of oil.

Our method for estimating the effect of a change to a country's spending on oil to the country's total income requires assuming that prices are constant during the disruption. We assume that the price per barrel of oil remains fixed at the pre-disruption price during the disruption. Allowing for the price to increase would cause our estimates of the impacts of oil disruptions to be larger.

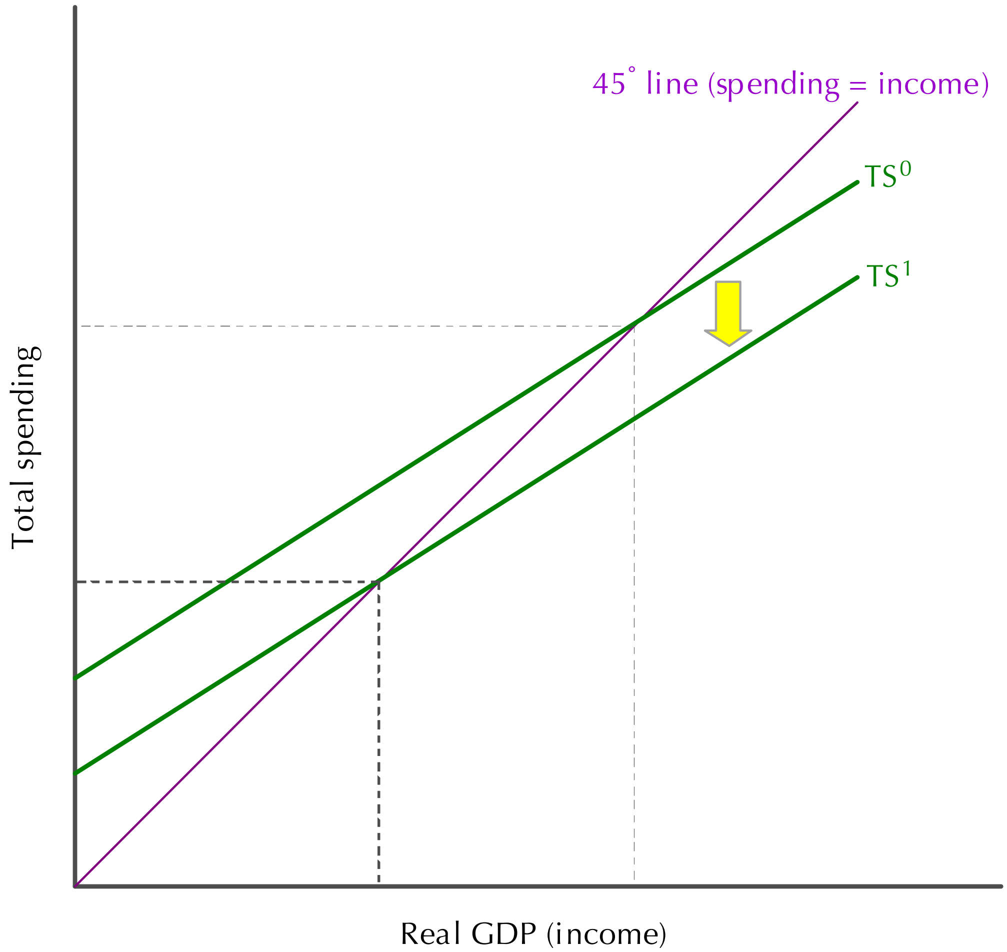
We assume the quantity of oil transported through a chokepoint to a given country is equal to the product of (1) the quantity of oil transported through that chokepoint that is received by the world, and (2) the ratio of the country's consumption of that oil to the world's consumption of that oil.

As we explain in appendix B, we use IO analysis to estimate how much the level of total spending will decline as a result of the decline in spending on oil. We use the Keynesian spending model—figure 4—to provide insight as to how the reduction in total spending (a short-run phenomenon) will translate into a reduction of income, measured by real GDP (a medium-run phenomenon).

The total spending curve (TS) illustrates how a country's spending varies with the combined incomes of its citizens.[23] We use our estimate of the change to total spending in order to see how much the TS curve shifts down. That is, in the short run (during the disruption), people will earn the same income, but spend less of it.

23. Because people do not spend every dollar of their income, the slope of TS is less than one. The y-intercept of TS is positive because people might consume out of their savings rather than out of their income.

Figure 4. Total spending in 'Country Z' before and during the disruption to 'Chokepoint A'



In figure 4, the 45-degree line represents all points at which the level of total spending equals total income. A Keynesian (or medium-run) equilibrium is defined by the intersection of the TS curve and the 45-degree line.[24] We use an estimate of the slope of the TS curve to estimate the change to real GDP caused by the shift of the TS curve. The

24. At this point, individuals have a level of income that does not yield an incentive to spend marginally more or less. The absence of marginal changes to spending also results in an absence of changes to incomes.

change to real GDP is greater than the initial change to total spending, as the graph suggests.

Mathematically, the Keynesian spending model is very tractable. The total spending function, or the relationship between total spending, *TS*, and disposable income, *Y*, is linear.

$$TS = \beta_0 + \beta_1 Y$$

As total spending increases with the economy's GDP, higher levels of income result in higher levels of total spending because consumption spending increases with income—$\beta_1>0$. We also assume that spending cannot change by more than income changes—$\beta_1<1$.

In our model, the equilibrium level of GDP is the level of income, Y^*, that results in GDP equalling total spending.

$$S^* = \beta_0 + \beta_1 Y^* = Y^*$$

After reordering the terms, we can solve for the equilibrium value of GDP in the medium run.

$$Y^* = \frac{1}{1-\beta_1} \times \beta_0$$

Assuming that β_1 is constant, the change to GDP caused by the change to total spending is

$$\Delta Y^* = \frac{1}{1-\beta_1} \times \Delta\beta_0$$

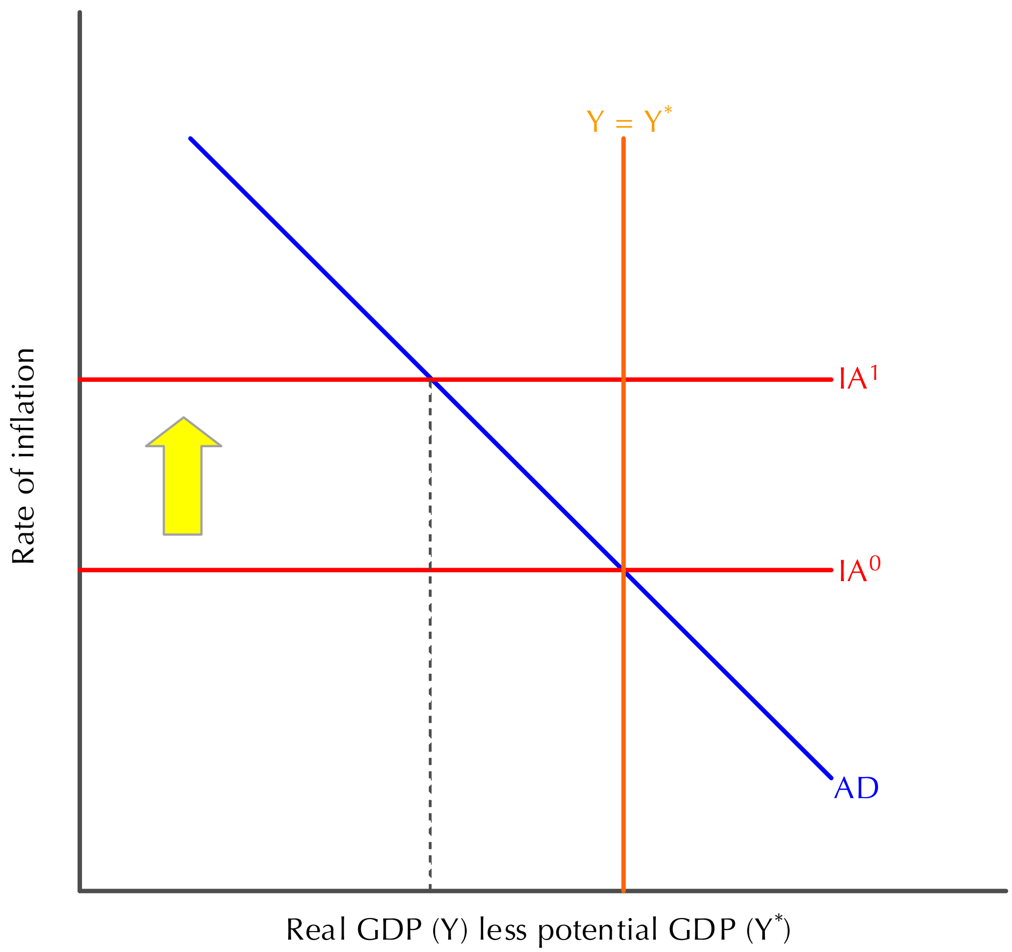
Because β_1 is bounded by 0 and 1, a small change in total spending is magnified into a larger change in GDP. This is called the multiplier effect.

Finally, we use the Aggregate-Demand Inflation-Adjustment model (AD-IA)—seen in figure 5—to understand how an oil supply disruption would affect GDP, inflation, and unemployment. The AD curve illustrates how, in the medium run (the quarter after the disruption), the rate of inflation affects the amount of total spending—and, therefore, income.[25] The IA^0 line indicates the present rate of inflation. An oil supply disruption eventually causes prices of final goods and services to be higher than previously expected; hence, the rate of inflation is expected to increase, and the IA curve shifts up to IA^1.

The interaction of AD and IA determine the value of real GDP. As we know from the Keynesian model, real GDP will decline in the medium run. From the AD-IA model, we know that this will be accompanied by an increase in the rate of inflation. We would also expect the country's unemployment rate to increase. By definition, when real GDP falls below potential GDP, the country's unemployment rate moves above its normal (benchmark) rate.

25. As the inflation rate increases, interest rates will rise (say, as governed by a central bank's monetary policy rule). Consequently, individuals will want to spend less on domestically produced consumption goods and capital goods (investment declines). Hence, there is an inverse relationship between inflation and aggregate demand.

Figure 5. GDP and inflation in 'Country Z' before and after the disruption to 'Chokepoint A'



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