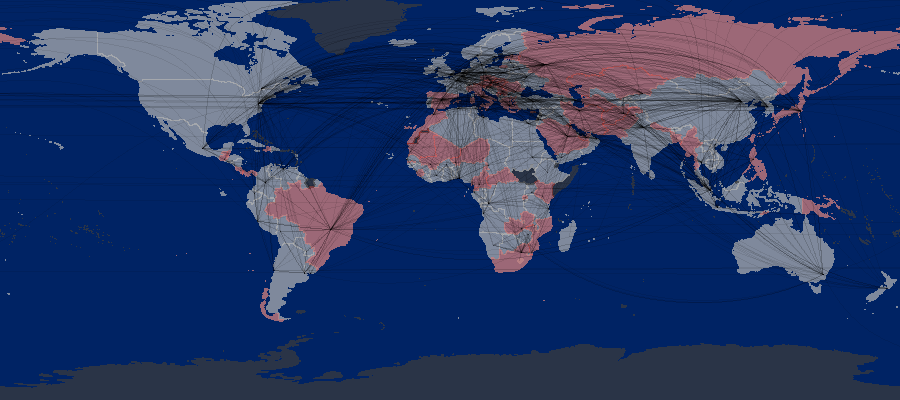
TOWARDS UNCONVENTION ANALYTICS FOR ENERGY SECURITY

Applying a data-driven computer simulation to forecasting energy security risks



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TARGET AUDIENCE: Policy analysts who are either producers or consumers of forecasts of international energy security.

**I. KEY POLICY QUESTION**

What risks to oil security are posed by cascading political supply shocks? Can they be identified using a computer simulation?

# II. EXSUM

Energy security is placed at risk when energy producers experience internal or external crises or conflicts. Crises in major consumers may also pose a risk for major producers who depend on energy prices for internal stability. The contagion of conflict from country to country increases the risk of widespread disruptions to the international oil system. Such risks may be mitigated by stockpiles and excess capacity. A computer simulation encodes these assumptions, combines them with data on the present international oil trade network, and generates ranges of notional future outcomes. It indicates that countries with limited trade relationships are most vulnerable to energy risks, that stockpiles are sufficient to address the majority of short-term shocks but that the probability of large-magnitude shocks must also be accounted for.

# III. TIME FRAME: Simulating the Long Present

The structure of the international oil markets change slowly. Major trade relationships remain largely stable from year to year, while reserves are discovered, brought online, and depleted slowly. While the root causes of crises (domestic grievances, regional instability) also change over years and decades, crises themselves can break out rapidly, with little warning. While some crises may go on for years (such as the Iran-Iraq war) others may end in weeks (the Venezuela general strike). Thus, the model simulates what I call the Long Present, the continuation of the current structure of the international oil system into the near future. Each tick of the model simulates one month, and each model run is 5 years (60 months) long, capturing the medium-term impact of short-term events.

# IV. ASSUMPTIONS

## SUPPLY SHOCKS

One key mechanism tying geopolitics to energy security is the mechanism of supply shocks. Generally speaking, a supply shock refers to a rise in oil prices due to an active disruption in production. Recent research suggests that oil prices are only loosely linked to supply disruptions [[CITE]], due to anticipation and speculation. Nevertheless, oil prices themselves are only an incomplete measure of energy security: if a major source of oil is disrupted, that oil (and the energy it contains) is unavailable. The majority of significant supply disruptions of the past decades have been driven by conflict and instability, from general strikes (Venezuela 2002-03) to all-out war (1980-88 Iran-Iraq War). It is such disruptions that this model focuses on.

## MODEL DESCRIPTION

The model consists of simulated countries on a world map, each of which has a set supply of and demand for crude oil, and a set network of trade partners. Each month of the simulation, countries experience crises with some probability, and these crises may spread to neighboring countries. When a country is in crisis, its participation in the international oil market is considered at risk, affecting both upsteam suppliers and downstream consumers. Optionally, countries may use their spare capacity to increase production in order to assist allies experiencing supply shocks, though this has the potential to glut the overall international market.

*See Appendix B for more detailed overview of the model.*

# V. ANALYSIS

## DRIVERS

The model is instantiated with data representing the current state of the world, which will remain fixed throughout the course of each model run. These data represent the 'drivers' of the analysis, the geopolitical and energy environment within which countries operate. The model describes the world in the following ways:

* THE OIL TRADE NETWORK is obtained from oil imports reported in the UN COMTRADE database for 2012.
* OIL SUPPLY AND DEMAND begin at total imports and outputs. For the top 10 oil producers, I incorporate IEA estimates of their consumption of domestic production.
* POLITICAL INSTABILITY data was obtained from the Economist Intelligence Unit's Political Instability Index [[CITE]]. Probabilities are set such that a country with a Political Instability Index value of 10 (the highest possible value) has an overall 80% chance of entering crisis over a two-year period.

There are two special cases, contagion and assistance, which remain fixed throughout each model run but may change between them, in order to model different ideas of how the world works:

* CONTAGION is the spread of instability or conflict. The topic of whether (and how) internal unrest spreads from country to country is still under active debate within the political science literature [[CITE]]. Thus, the model explores both futures where conflict contagion occurs and when it does not.
* ASSISTANCE here is the ability of major oil exporters to rapidly increase production in order to counterbalance loss of secure oil elsewhere in the system.

## VARIABLES

Energy security is determined by many variables that change over time. Some of these variables are under countries' control, some involve the complex interactions between countries, while others still depend on the varagies of chance and science. Only a small subset of these variables have been incorporated into the model to date, but there is no reason that more could not be included as well.

### MODEL VARIABLES

* CRISES are the key variable that determines each country's energy security at different times. In the model, crises arise at random as described above: countries cannot intentionally affect or prevent them. Theoretically, however, a country's ability to prevent crises is factored into its stability index. Thus, crises can be treated as occuring when these efforts fail.
* LENGTH OF CRISES is randomly drawn from a power law distributions. Powe laws are known to characterize inter-state conflicts, terrorist attacks, financial crises and other complex events. Power laws have small-magnitude events more likely than large-magnitude ones, with an important caveat – the large values remain possible, and in fact may be arbitrarily large.
* SPARE CAPACITY refers to countries' ability to *rapidly* increase oil output in response to a crisis. The main country for which this is relevant is Saudi Arabia, which has claimed an ability to increase output by up to 25% if needed. This ability is modeled as follows: if country B imports oil from country A and experiences a supply shock, AND country A is not itself in crisis, A will increase its output with a probability equal to B's share of A's exports. Thus, the more important B is to A, the greater the likelihood that B will assist it. The production ramp-up is temporary, and will cease as soon as A ceases to experience a supply shock. Since oil is fungible, this temporary increase in production affects not only the country in supply shock, but all of A's trade partners.
* ENERGY SECURITY is the model’s ultimate output, measured by three ratios:
  + **Import Demand / Supply** is the primary measure of energy availability. It is simply the ratio of a country's (fixed) total demand to the sum total of its imports from countries that are not currently in crisis. The baseline for this ratio is 1. As oil sources enter crisis, the ratio will increase, as demand outpaces safe supply. If another country increases its oil production (as described below), the ratio may dip below 1. This captures situations when a release of reserves may in fact create a glut of oil, particularly in countries which are less affected by ongoing crises. If the ratio rises above a predefined threshold, a country is considered to be experiencing a SUPPLY SHOCK.
  + **Export Demand / Supply** is a measure mostly relevant to large oil exporters, and measures the ratio of overall production-for-export to the demand by trade partners who are not themselves currently in crisis. This measure is primarily in place to capture the risk posed to major exporters by demand shocks [[CITE]], which risk pushing the price of oil below a break-even point [[CITE]].
  + In addition, the model tracks a global **Current Demand / Current Supply** ratio: the sum of demand from all countries not currently in crisis divided by the sum of all exports from countries not currently in crisis. This is meant as an approximate proxy for the price of oil.
  + CONSUMPTION OF DOMESTIC PRODUCTION refers to the fraction of domestic consumption coming from domestic production -- in other words, the fraction of demand that is secure from external supply shocks. While treated as fixed in the model (at least from run to run), in reality this is a variable that many countries do have control over. In practice, this variable is primarily relevant to countries where oil production is large relative to domestic demand.

### OUT-OF-MODEL VARIABLES

As noted above, many variables that influence a country's overall energy security are not included in this model. Some of the major ones are: NON-OIL ENERGY, countries’ mix of energy sources, which increase or decrease the importance of oil to its energy security; OIL TRANSPORTATION from producers to consumers, including choke points such at the Straits of Hormuz and Malaca; REFINERIES which convert crude oil into petroleum and other consumable products; and INTERVENTIONS, military and otherwise, which may help alleviate supply shocks, or end up exacerbating them. Finally, by assuming the Long Present, the model excludes the slow but steady CHANGE in the international oil system.

### WILD CARDS

While most systemic changes are likely to take time to take effect, there are several 'wild card' scenarios that would likely rapidly reshape the system outside the envelope of the Long Present. These include:

* SIGNIFICANT GEOPOLITICAL REALIGNMENTS involving major oil producers and reshaping the trade network and instability risks (e.g. an end to Western sanctions on Iran).
* MAJOR CONFLICT, such as a war between the US and China, may substantially shift global demand, put major shipping routes at risk, and potentially change the trade network as well.

## MODEL ANALYSIS

Each run of the model yields one simulated future scenario – one possible alternative outcome. Repeated runs yield a range of possible outcomes, which I analyze to estimate different potential energy security futures.

### GLOBAL OUTCOMES

Overall, the peak of the distribution of estimated energy security metrics across all scenario-months is close to 1 – a balance between supply and demand for secure crude oil. This is comforting, both in terms of the model’s validity and its predictions: it does not anticipate massive future oil shocks. The model yields scenarios of both excesses and shortfalls in secure supply compared to demand, but not in equal proportions – supply shortfalls are more likely, and more extreme, than major demand shocks. Specifically, global demand outpaces supply by a factor of 25% or more in XX% of scenario-months, while supply outpaces demand by the same factor only XX% of cases. More extremely, supply outpaces demand by 50% or more XX%, compared to XX% for vice versa.

I also characterize the path each scenario takes across its 60-month run by examining the average demand-supply ratio, and its variance (how much it deviates from that average). There is only weak correlation between the two: some scenarios see high ratios but low variance, where energy supplies are insecure but *stably* insecure, while others see averages close to 1 but high variance, with wild swings between excess demand and excess supply.

#### EFFECTS OF CONTAGION AND ASSISTANCE

I also compare the outcomes of simulations with the two variable drivers Contagion and Assistance turned on and off, and conclude that their effects exist, but are small in magnitude. Specifically, the possibility of conflict contagion increases the average ratio by approximately 2%, and the variance by 14%. It also increases the probability of a severe supply crisis by approximately 50%, though the probability is still low, occurring in just under 5% of scenario-months. Note, of course, that this refers to the possibility of contagion overall – the risks posed by the contagion of a particular conflict in a particular region will vary, and may be significantly lower or higher.

When countries have the possibility of assisting others by rapid short-term production increases, both the average and variance ratio is reduced by under 1%, while the probability of severe supply crises remains essentially unchanged. In other words, assistance may alleviate minor or temporary supply shortfalls, but not major shocks. In fact, such shocks are most likely to be caused by crises in precisely the countries capable of the largest short-term production increases, primarily Saudi Arabia and its neighbors.

### COUNTRY-SPECIFIC OUTCOMES

#### SUPPLY RISK

Figure X, in Appendix A, shows the supply risk to each country in the model, across all the simulated scenarios; specifically, the darker the color, the greater the risk of a major supply disruption. One factor that stands out is that several of the countries at greatest risk are themselves major oil producers: Canada, Mexico, Iran, and (to a lesser extent) Saudi Arabia. There are two things going on here: these countries import oil from relatively fewer countries, making them more vulnerable to disruptions. While the risk may be somewhat overestimated if these countries can divert domestic production to domestic consumption, this itself would have a major impact on the international oil system. Furthermore, Iran in particular does not have the domestic refining capacity to satisfy its domestic demand, limiting its ability to consume its own output. It is also possible that major oil producers are less vigilant than other countries about the security of their imports, precisely due to their domestic capabilities. Compare this to Europe’s relatively lower risk, and the United States’s only somewhat higher risk. China, in contrast, has the greatest risk among countries that are not major exporters – likely reflecting that its high demand requires it to import oil from wherever it can, without as great an emphasis to security.

There is a wide distribution in the mean and variance of supply ratios of different countries across all the model realizations. Not surprisingly perhaps, the most vulnerable countries tend to be smaller and poorer, while the least vulnerable countries are more likely to be developed. There are some surprises: for example, Venezuela is an extremely high-risk country despite being a major oil producer. This may be due in part to missing data on Venezuela's consumption of its own production; however, it also highlights that domestic production is not itself a sufficient guarentee of energy security. To a much greater extent than for the global-level analysis, country-specific variance correlates strongly and positively with mean supply ratios. This means that for individual countries, uncertainty and insecurity go hand in hand.

Overall, the United States oil supply ratio is most likely to be close to 1. However, there is approximately an 8% probability of a serious supply crisis (ratio > 2) occuring at least once in the timeframe of the model, and a ~1% probability of a catastrophic crisis (ratio > 4). In comparsion, China has a slightly larger probability (10%) of smaller supply crises, but under no scenario experiences shocks as extreme as the US's most extreme ones.

# POLICY RECOMMENDATIONS

* The energy security situation of any specific country does not necessarily track with global energy security.
* Diversity in both imports and exports is vital to energy security.
* Reserves and excess capacity help mitigate the risks of the majority of crises.
* Policymakers should be prepared for low-probability, high-impact events, particularly those arising from multiple simultaneous political crises.
* Computer simulation provides a method of extracting quantitative information from a qualitative understanding of the world, and can generate ranges of scenarios and future outcomes.

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