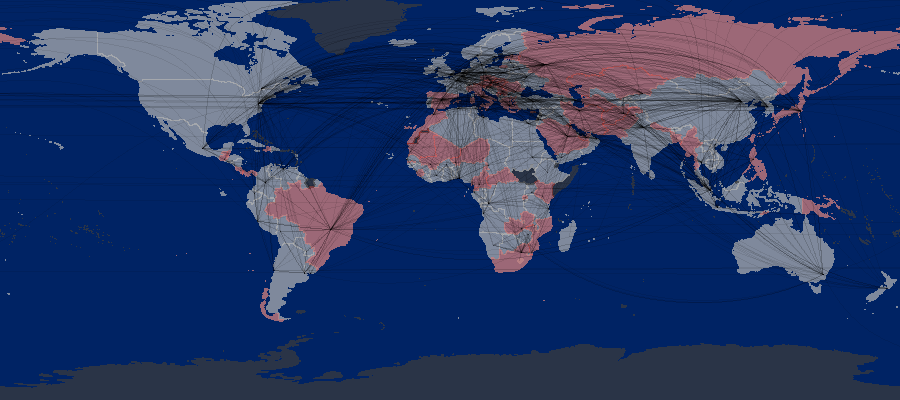
**TOWARDS UNCONVENTION ANALYTICS FOR ENERGY SECURITY**

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 political supply shocks? Can they be identified using a computer simulation?

# II. EXSUM

International political crises and conflicts are the main drivers of oil shocks, and this is unlikely to change as energy security becomes an increasingly important issue. Yet despite the complex, dynamic nature of the international system, most formal analyses of energy security are largely static. I propose a new, 'unconventional' approach, leveraging data from multiple sources and operationalizing qualitative assumptions into a dynamic computer simulation modeling international energy security. The model estimates that there is an approximately 10% probability of an international oil shock within a 5-year timeframe; it suggests that Russia and Eastern Europe are at particular risk from supply shocks, and that the major oil producers in the Americas besides the United States are vulnerable to demand shocks. It indicates that conflict contagion does not pose a large risk to oil security, and demonstrates that the spare capacity maintained by Saudi Arabia and the Gulf states may not mitigate against major supply shocks.

# III. TIME FRAME: Simulating the Long Present

The structure of the international oil markets changes slowly. Major trade relationships remain largely stable from year to year, and 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, others may end in weeks. 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 (Kilian 2008), 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 (e.g. Venezuela 2002-03) to all-out war (e.g. the 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 supply of and demand for crude oil, and a network of trade partners. Each month of the simulation, countries may 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 upstream suppliers and downstream consumers. Countries may also 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 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 and other estimates of their consumption of domestic production.
* POLITICAL INSTABILITY data was obtained from the Economist Intelligence Unit's Political Instability Index. 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 (Black 2013). 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 utilize their spare capacity 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 vagaries 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 affects energy security. In the model, crises arise at random, and countries cannot intentionally affect or prevent them. A country's ability to prevent crises is factored into its stability index and thus crises can be treated as occurring when these efforts fail.
* LENGTH OF CRISIS is randomly drawn from a power law distribution. Power laws are a probability distribution known to characterize inter-state conflicts, terrorist attacks, financial crises and other complex, rare events (Cioffi & Midlarsky 2004). Figure 1 in Appendix A illustrates the power law used here.
* 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.
* 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 (Daya 2013). 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 A 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:
  + **Supply Ratio** is the primary measure of energy availability. It is simply the ratio between a country’s total demand and the sum total of its domestic consumption (if any) and imports from countries that are not currently in crisis. The baseline for this ratio is 1. As oil sources enter crisis, the sum of secure imports decreases and the ratio will increase. If another country increases its oil production, however, 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 that are less affected by ongoing crises. If the ratio rises above a predefined threshold, a country is considered to be experiencing a SUPPLY SHOCK.
  + **Demand Ratio** 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 that risk pushing the price of oil below a break-even point (Stevens 2013).
  + In addition, the model tracks a global **Current Demand : Current Supply** Overall 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.

### 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 Malacca; REFINERIES which convert crude oil into petroleum and other consumable products; and INTERVENTIONS, military and otherwise, which may help alleviate 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, 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.
* NATURAL DISASTERS also pose a risk to oil supplies that is not captured by the stability index. Major disasters may affect all elements of energy security, including production capacity, shipping, and demand.

## 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

The initial analysis is the distribution of the Overall Ratio across all simulated months of all scenarios, shown in Figure 2. The peak of the distribution is close to 1, showing that a balance between supply and demand for secure crude oil is the single most-likely outcome. This is comforting, both in terms of the model’s validity and its predictions: it does not anticipate massive future oil shocks to be very likely. 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 11% of scenario-months, while supply outpaces demand by the same factor only 3% of cases.

I also characterize each scenario by examining the average demand-supply ratio across all 60 months, 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 secure energy supplies are scarce but stable, while others see wild swings between excess demand and excess supply which nevertheless average out – possibly more secure in terms of absolute oil available, but far more unstable and less certain.

#### Effects of Contagion and Assistance

I 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 1%, though it increases the variance by 17%. It also increases the probability of a severe supply crisis, though the probability is still low, occurring in just over 1% of scenario-months. Note, of course, that this refers to the possibility of contagion overall – the risks posed by the contagion of a particular crises 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, overall energy security is essentially unchanged. While assistance may alleviate minor or temporary supply shortfalls, it does not appear to have a broader impact. Note that major supply 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; if these countries are driving a supply shock, other countries may not be able to increase their own production enough to counterbalance them.

### Country-Specific Outcomes

#### Supply Risk

Figure 3, in Appendix A, shows the risk of major supply shocks to each country in the model, across all the simulated scenarios. Not surprisingly, we note that the major oil producers appear to be at the least risk (not least due to their consumption of their own domestic production, reducing their reliance on imports), while the developed world faces comparatively higher risks. Russia stands out as a major oil producer that also faces significant supply risk. While it is certainly possible that this estimate is being driven by incomplete data on Russia’s notoriously opaque oil economy, it may also be evidence that Russia’s oil imports are driven as much by geopolitical considerations as by a desire for a secure energy supply.

We also notice that much of the ‘Global South’ appears more vulnerable to supply shocks than much of the developed world. These countries are likely to have less diversified oil imports, and even the ones endowed with significant oil of their own (such as Brazil) may not be able to satisfy growing domestic demand with domestic production. When these countries are economically and politically fragile, major oil shocks have the risk of having a greater impact on their political stability and human security, potentially triggering additional crises and further cascading instability (a possibility not yet incorporated into the model).

#### Demand Risk

The first thing we notice examining Figure 4, the visualization of the risk of major demand shocks by country, is that it is overall lower than supply risk. This should not be surprising, as fewer countries are major oil exporters. The risk to the major Persian Gulf producers appears low – they are wide exporters, and many of their largest trading partners are relatively stable developed nations. Interestingly, the major non-US producers in the Americas, Canada, Mexico and Venezuela, all have relatively high risk. This appears to be driven by the disproportionate fraction of their exports purchased by the United States. While the US is relatively stable, any disruption of US demand would have a disproportionate impact on these countries. Note that Russia’s demand risk is relatively low – an important finding in light of the outsize importance of energy exports to the Russian economy.

# VI. POLICY RECOMMENDATIONS

* Under present conditions, global energy security is likely to remain stable
  + However, policymakers must prepare for low-probability, high-impact contingencies.
  + The spare production capacity maintained by the Gulf states cannot mitigate extreme supply shocks.
  + Conflict contagion as a general phenomenon does not pose a significant risk to energy security.
* Consumption of domestic production provides strong protection from exogenous oil shocks, even in the absence of complete energy independence.
* Diversity of both imports and export partners is critical to energy security.
* Developing countries show greater vulnerability to oil shocks than developed countries.
* Russia and Eastern Europe appear particularly vulnerable to supply shocks.
* Major American oil exporters excluding the United States show relatively high vulnerability to US-driven demand shocks.
* The Gulf oil producers do not face significant crisis-driven demand risks.

### Modeling Conclusions

* The computer modeling approach successfully combines qualitative assumptions and quantitative data in order to produce meaningful estimates of energy security.
* Even a stylized model requires extensive data from different sources.

# Appendix A: Figures

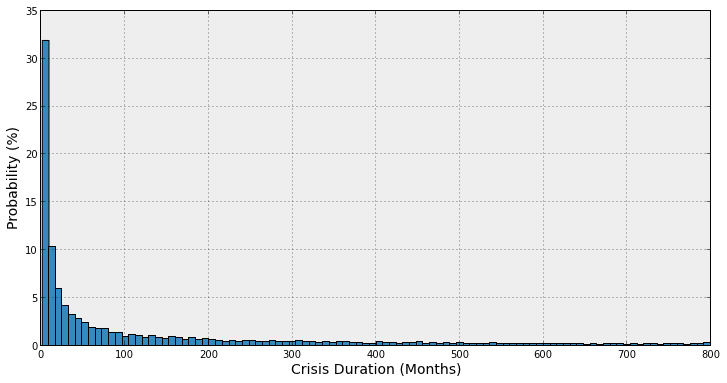


Figure 1: Power law distribution of crisis duration

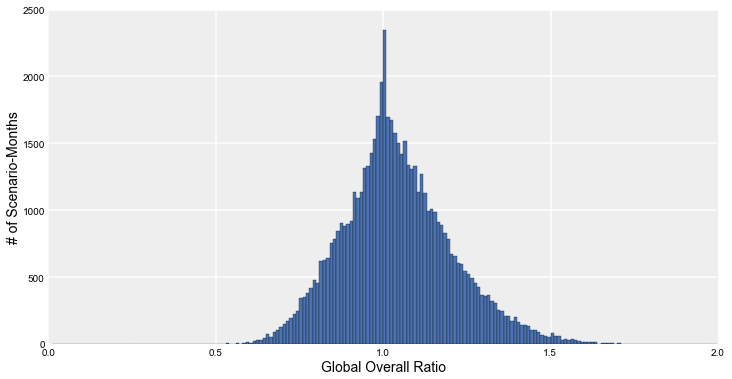


Figure 2: Simulated distribution of Overall Supply to Demand ratio

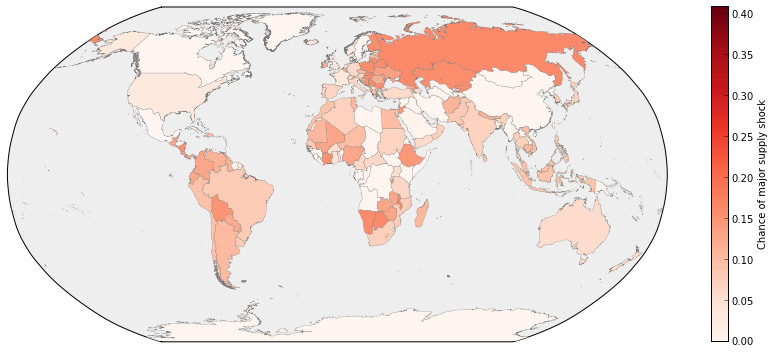


Figure 3: Simulated risk of major supply shock, by country

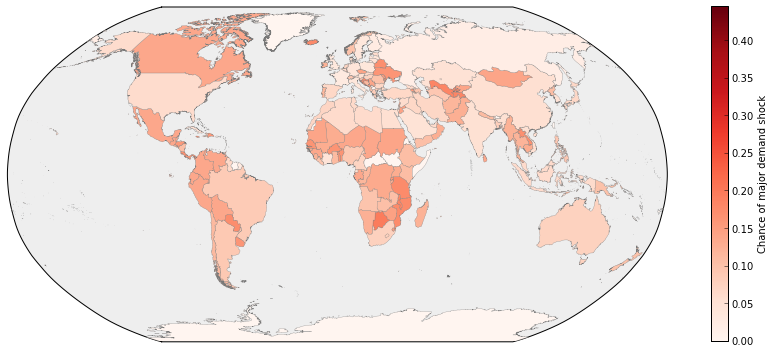


Figure 4: Simulated risk of major demand shock, by country

# Appendix B: Model Summary

* Each agent in the model represents a geolocated state. States have a fixed network of trade partners, total demand (satisfied by imports and domestic production), spare capacity, and a political stability index.
* Each tick of the model (representing one month), a state that is not in crisis may enter crisis with a fixed probability based on an estimate of its stability. The crisis length is drawn from a power law distribution with a coefficient of -1.37.
* If the Contagion option is activated, a crisis may spread from a state to its neighbors with probability equal to the neighbor’s stability index.
* When a state is in crisis, its participation in the international oil market is considered at risk, both as an importer and exporter.
  + The model measures the ratios of oil supply and demand that are not at risk, both state-by-state and worldwide, as indicators of energy security.
* If the Assistance option is set, and a country is experiencing a supply shock, its trade partners may temporarily increase their own production in order to alleviate the shock with probability equal to the original state’s fraction of the assisting state’s exports.
  + This increase affects all the assisting state’s partners, whether or not they are experiencing a supply shock.
  + As soon as the supply shock subsides, the assistance stops and export volumes return to baseline

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