HOW THE QUEUING THEORY EXPLAINS VOLATILE OIL PRICES

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ABSTRACT

This paper makes the connection between the gap in global oil demand and supplies and a commonly used systems theory, the Queuing Theory. Major shocks and oil markets will be analyzed for the United States, China, and India. Current trends show that this gap may narrow in future years and when using the Queuing Theory to describe this system, shocks to the system may become more frequent and of greater magnitude in years to come. Three parts of the oil market (Demand from consumers, supply from oil producing countries and the capacity of refineries) are analyzed.

Keywords: Oil, Queuing Theory, Globalization, Refinery Capacity, Energy Prices

INTRODUCTION

The Queuing Theory is frequently used to describe how supply and demand interact in terms of either smooth functioning or when disruptions affect normal systems operations. Traffic patterns are often mentioned to illustrate Queuing Theory. If a traffic control system is operating at 70% capacity, any minor disruption to the operation can have a major impact on the natural order. An example would be how a minor traffic accident causes a major traffic jam. One minor event that should have a small impact ends up bringing a system to a standstill. The principles of the Queuing Theory can also be utilized when banks must determine how many teller windows to keep open to serve customers during lunch hours or for supermarkets to determine how many cash registers to keep open during the evening (Businessmanagementcourses.org). Under Queuing Theory, we are currently experiencing an energy system that is operating well beyond normal capacity thresholds and in which any disruption, be it violence in Nigeria or civil unrest in a small country like Libya, could have major implications for the world energy market. This pattern is represented by the volatility in prices for a barrel of oil immediately after these disruptions.

This paper will seek to show that a consistent growth in demand and the volatility of oil supplies has had a major impact on our world economy. This fragile market creates a situation where "shocks," or extreme movements in price, occur more frequently than one would expect in a normally distributed supply/demand market under Queuing Theory. Energy problems can be caused by disruptions from all types of energy supplies, such as coal and natural gas. However, this paper will focus on oil, as 35% of worldwide energy use comes from this source (Energy Information Administration, 2006). It is also a commodity about which consumers can see disruptions very easily as prices are updated daily at local gas stations. The volatility in prices represents the correlation between supply side disruptions and increased demand. The current system is operating beyond what it was originally set up to do. Therefore, a more effective and comprehensive energy policy needs to be implemented to ensure stability in energy supplies in the United States. At several points in recent history, including the oil embargo in the 1970s, the aftermath of Hurricane Katrina and the summer spikes of 2008, prices of oil have skyrocketed due to disruptions in the supply of oil.

In a queuing system, there are two parts that must be classified. First, the demand for oil will be classified as arrivals in a queuing system. Arrivals are the requests in a system that must be processed in order for the system to operate and function correctly. For the purpose of this example, we can assume that the first in-first out rule can apply to matching the demand to the given supply, and that these arrivals are independent and act accordingly. While these assumptions are not much of a stretch when the system is operating properly, in times of crisis or increased volatility in the market, these parameters may become problematic. The other side of the equation comes from the supply and relates to how the oil industry can be explained using the Queuing Theory. The supply will not only be concerned with how much oil is coming out of the ground, but also will need to look into the refining capabilities for the industry overall. This relationship of inputs and processing shows an output of waiting times. When related to the oil industry, this can be represented by the price of oil. As the percentage of capacity utilization increases linearly, arrivals will have longer waiting periods, growing exponentially. This acts counter-intuitively to the idea that when demand increases linearly, the wait time should act in a similar manner. However, in practice this is not how our energy system is set up to function. In the oil markets, small disruptions lead to vastly higher oil prices. In order to examine these relationships, a Poission distribution can be utilized to manage the independent arrivals and processes.

In 1973, 35% of U.S. oil consumption was supplied by foreign imports. By 2010, this percentage had grown to 45% as 8,742,000 barrels (U.S. Energy Information Administration, 2011) of the 19,150,000 barrels of oil consumed daily in the U.S. (CIA, 2011) were imported. This means that international events and relationships are increasingly having huge impacts on how America's oil, and energy overall, will be priced. One of the major increases in oil prices occurred after OPEC decided to establish an oil embargo against the United States in response to its decision to support Israel in the 1973 Yom Kippur War. The average price of a barrel of oil in 1970 was $19.65, inflation adjusted for 2011 prices. For the year following the announcement of the OPEC oil embargo, the average inflation adjusted price was $42.58 (InflationData, 2011). This is more than a two-fold increase in price and a large portion of that increase should be attributed to the decrease in available oil. This limited supply, or ability to process inputs, played a major role in the increase of oil prices in 1974. The amount of oil supply has been and continues to be an explosive point between oil producing and oil consuming countries. However, this is not the only factor that should be analyzed for processing oil demand.

Refinery capacity plays a major role in the capabilities of processing demand. When capacity in refineries decreases, the utilization rate will likely increase (assuming demand remains constant). As can be seen in Figure 1, as the available capacity is reduced, the waiting time, or price of oil, increases rapidly. The reduction in available capacity has frequently led to a large increase in the price of oil. The available capacity can be attributed to the waning support for building new refineries in the United States. While oil refineries have experienced increased efficiencies and thus higher capacities, there have been no new refineries in the U.S. since 1976 (McGillen, 2010). The environmental effects of refineries have led many groups to oppose new refinery construction for over 30 years. Because of the environmental concerns that the public has for building increased refinery capacity, legislators have stayed away from pushing an energy agenda that includes new refineries. However, in order to create a comprehensive energy plan and to avoid volatile swings in prices, Americans will need to take steps to improve processing capabilities for increased demand.

Both political and weather related issues have significant impact on refinery capacity. A representation of how weather can affect prices was represented in oil prices before and after Hurricane Katrina (Pan, 2005). The area in the Gulf of Mexico where this hurricane struck is a major hub for oil refineries and the hurricane damaged or temporarily shut down much of the capacity in this region. Crude oil has a lot of potential energy, but the raw product needs to be processed and separated into multiple parts before it can be sold to consumers at retail locations. These parts can include, but are not limited to, gasoline, diesel fuel, kerosene and heating oil (Hargreaves, 2011). So while we must look at the international politics of dealing with productions quotas from OPEC, there also should be a major emphasis on refining the product in the Gulf of Mexico.

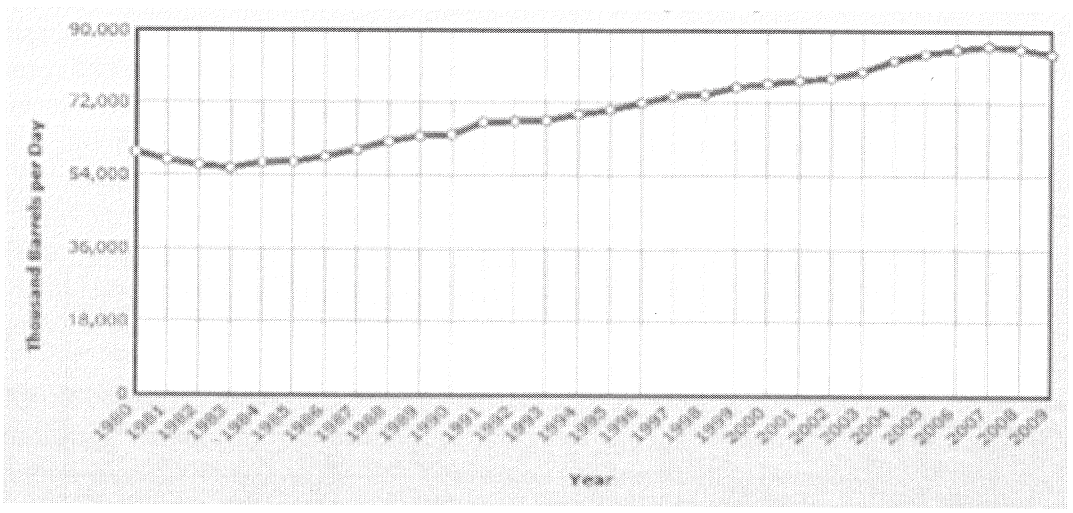
REFINING THE PRODUCT

The second step in providing a steady supply of oil to consumer markets depends largely on refineries and their ultimate capacity to process crude oil. Worldwide refinery capacity is 91.8 million barrels per day, and the United States has a refining capacity of 17.6 million barrels per day (British Petroleum, 2011) with 23% of that capacity located near the Gulf of Mexico, or close enough to be shut down due to Hurricanes Katrina and Rita which struck that area in 2005. Figure 1 below represents a gradual increase, by year, in the demand for oil globally

(IndexMundi.com, 2011). However, if refining capacity remains constant, then operation at such high levels should set off alarms. This is because as demand increases, the excess capacity available will lessen year by year. Whenever a major storm forms in the Gulf, these refineries are shut down as safety precautions. With a six-month hurricane season, this can create huge headaches. As seen after Hurricane Katrina, it can cause major disruptions.

Following the destruction of Hurricanes Katrina and Rita, many of the refineries in the Gulf of Mexico needed to be shut down. These hurricanes caused 73% of offshore production to be halted in the Gulf and 23% of the U.S. oil refinery capacity to be closed temporarily (Reuters, 2005). This caused oil prices to rise to $70 per barrel, just before President Bush decided to release 30 million barrels of oil from the Strategic Petroleum Reserve (Pan, 2005). This act of selling reserves from the Strategic Petroleum Reserve is one of only eight times oil has been released for sale (Department of Energy, 2011). At the time, the world was consuming 85 million barrels of oil per day, while refinery capacity was only 1 million barrels above this amount. This means that the world was operating at 98.8% of its operating maximum amount.

FIGURE 1: Global Demand for Oil



As discussed earlier, serious logjams can result from minor problems during operations at 70-80% of maximum capacity. With capacity operating at 98.8%, it is easy to see potential for disaster from any disruption. Any small bump or turn in the road can cause huge market pitfalls and large swings in the price for oil. The question is, 'At what point will consumers be deterred from demanding a product or service and begin to search for substitutes?' For example, if you arrived at a restaurant and saw that the waiting time was ten minutes, you would likely wait it out, assuming you desired that specific product. However, what if the waiting time increased to an hour, two hours, etc.? This can be related to a consumer's level of desire to purchase oil as the price of oil increases. At a 20% increase, would consumers change their behavior drastically or would they still drive to work without a carpool and still take lengthy family trips? What if the price of gas per gallon doubles? Would you then see demand begin to ebb as consumers see a larger hit to their discretionary spending? As the waiting time increases, you will likely see a decrease in demand and a pursuit of substitutes (i.e., alternative fuels, choosing not to use product), but these substitutes can often take longer periods of time to adjust to. Therefore, in the short term, demand will remain constant as it will be difficult for consumers to adjust. With a reduced capacity and relatively constant demand, there is a potential for prices to skyrocket in the oil market.

Table 1, Global Refinery Capacity (BP Statistical Review of World Energy June 2011) highlights a modest increase in refinery increase over the last 10 years from 82.4 million barrels of oil per day to 91.8 million barrels. This increase is equivalent to an 11.3% increase in oil supply capacity. Worldwide oil demand in this same period has risen 17.7% from an average of 75.8 million barrels of oil per day in 2000 to 89.2 million barrels per day (International Energy Association, 2011). If demand continues to rise at a faster rate than supply capacity, crises in the oil and energy market will become more frequent. While the American refinery capacity has remained relatively constant during this ten period with a growth rate of 6%, areas such as the Middle East (21.9%), China (87.2%), and India (66.9%) have made great strides to increase their refinery capacity to meet their local demand. This is important for the world market, because as the U.S. continues to block the development of more refineries, the Asian Pacific region is gearing up for a much increased supply. In one way this helps ease the stress of refineries running at high percentages of capacity in the U.S. However, in addition to the U.S. consumer dependence on foreign pumped oil, there may also be a higher dependence on foreign refined oil.

TABLE 1: Global Refinery Capacity

	2000*	**2010***	**Change**	**2010 Share of Total**
North America	19,937	20,971	5.2%	22.8%
United States	16,595	17,594	6.0%	19.2%
S.&Cent. America	6,271	6,707	7.0%	7.3%
Europe&Eurasia	25,399	24,516	-3.5%	26.7%
Middle East	6,491	7,911	21.9%	8.6%
Africa	2,897	3,292	13.6%	3.6%
Asia Pacific	21,478	28,394	32.2%	30.9%
China	5,407	10,121	87.2%	11.0%
India	2,219	3,703	66.9%	4.0%
WORLD TOTAL	**82,473**	**91,791**	**11.3%**	

*Thousand barrels daily

DEMAND OUTPACING SUPPLY

A major representation of how demand can affect the system came into play in the rapid increase in oil prices in 2008. In 2007, we saw an average price of oil at $69.51, but this increased to

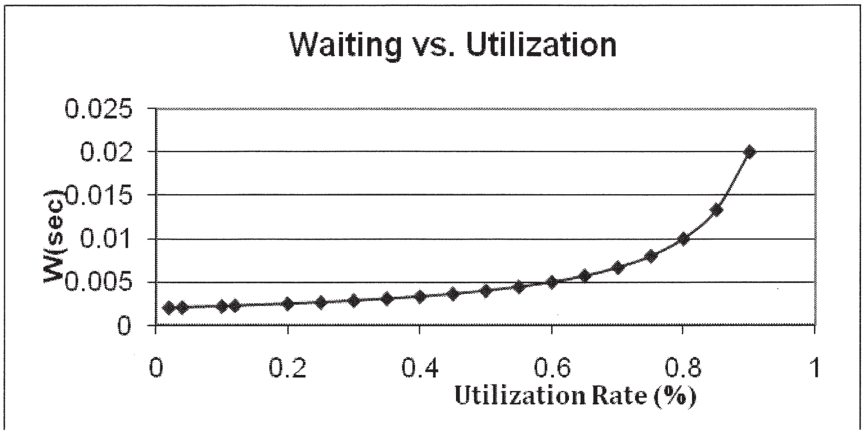
$95.25 in 2008 (InflationData.com, 2011). This energy crisis resulted in a 37% average increase in oil prices. This increased demand can likely be attributed to two main areas of considerable growth in the world, China and India. The world has seen a significant rise in demand in Asia as China increased its daily demand by 79% and India by 40% over the last ten years (Nationmaster, 2011). This plays a large role in the overall demand in the world and the effect on prices. As major importers of oil, the United States can't ignore the effects that a worldwide increase in oil demand will have on prices domestically. As the thirst for economic expansion is mirrored with more energy consumption in China and India, the world will likely continue to see high rates of oil demand as a result.

Looking to the near future, we should look at the concerted efforts in China and India to upgrade their infrastructure as this will ultimately lead to a higher demand for cars and thus oil. Both of these countries have made it a priority to expand economically, and infrastructure investments are a great way to aid this process. In 2010 alone, China sold 18 million cars (Nasdaq, 2011) and India sold 2.5 million cars (News24, 2011). With a middle class in India equal to about 250 million people, this number will likely continue to grow and the demand for oil will rise as well. If economic prosperity and standards of living are any indication of the amount of cars a country has, a 9% growth rate in China and 7% growth rate in India (Frangos & Anand, 2011) mean that these countries should see an explosion in the amount of cars in each country and thus an increase in their demand for oil. These increases in energy use from all parts of the globe will have a major impact on the price and availability of oil. It is very reasonable to assume that without a significant increase in the supply of oil or without a breakthrough technology that lowers our dependence on oil, we will continue to see higher prices for oil over the foreseeable future. The current gap between demand and supply is expected to narrow over the next decade unless significant steps are taken to adjust the situation. The narrowing in the gap between supply and demand will likely lead to higher volatilities in oil prices as the system is maintained at a level well above a manageable threshold.

As a result of higher oil prices, there will be a point where consumers try to move to other energy sources, which can result in higher energy prices across the spectrum of available options. For a nation like the U.S., which has built itself on consuming large amounts of cheap carbon-based energy sources, this creates a dilemma. On the one hand, consumers will continue to utilize the cheapest available energy source and will thus be resistant to making a switch to more expensive renewable sources of energy. However, if steps are not taken to invest in refineries now, the volatile effects in the future can have devastating effects on the economy.

The next question is, 'How can a relationship between the markets for oil and the Queuing Theory be explained?' In order to explain this, certain assumptions must be made. When the Queuing Theory refers to a system and a given threshold percentage, it is essentially establishing a point where backups will occur because waiting time grows exponentially as demand grows linearly. The Queuing Theory establishes different parts of the system, such as arrivals and the process of these arrivals. The first area of concern is what percentage of the maximum capacity of the system is being used for processing. The Queuing Theory approximates that once you reach about 70% of the capacity, the processing wait times for these arrivals increases exponentially, as shown in Figure 2: Queuing Theory – Utilization versus Waiting Time (Rutgers University). Certain assumptions need to then be made in order to match the Queuing Theory to how the oil industry is currently functioning.

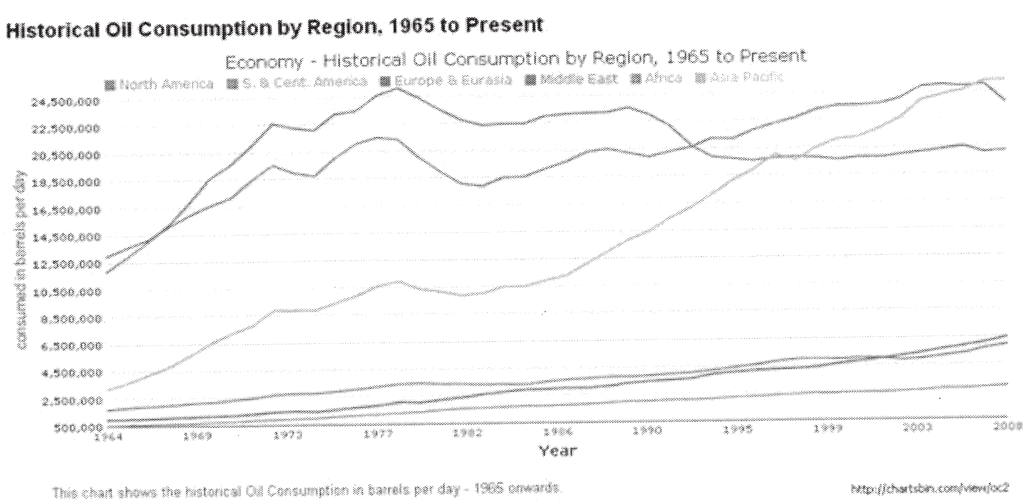
FIGURE 2: Queuing Theory – Utilization versus Waiting Time



When reviewing oil prices, we should be looking at the standard deviation (volatility of the commodity) and how often we see jumps in prices that are multiples of this number. For example, it is unlikely that a normal distribution would see a jump in price of three standard deviations from the mean. However, oil prices frequently move in these large amounts. How can this be explained? It is likely that the movement of oil prices does not follow a typical normal distribution, but instead follows a distribution with very "fat tails." A "fat tail" means that this distribution is more likely to see large jumps and price movements that are farther away from the mean, as compared to a standard normal distribution. If oil prices changed with a normal distribution, we would see prices increase at least a full standard deviation above the mean 60 days in a year. Increases of two standard deviations would be even rarer, as they would only occur 8.3 times per year. If oil has been trading at an average of $80 over the past year, and the standard deviation was $5, a movement equal to three standard deviations would be $80 + 2*$5 = $90. However, over the last fifteen years, the markets have seen movements of at least this amount, an average of 10.5 times per year (U.S. Energy Information Administration, 2011). This indicates a move from the standard normal distribution. It is likely that the distribution of oil is dispersed according to a distribution with much fatter tails. This implies that a larger percentage of the movements occur farther away from the mean. The cause can be that as markets frequently move in correlation, and as demand or supply are also affected, the markets over react. This means that they will over sell off oil, or in situations detrimental to the consumer, will begin to buy up more oil for fear that there will not be enough available to meet consumer demand (U.S. Energy Information Administration).

There are many contributing factors as to why our world is experiencing a much higher demand for oil, as well as why supplies have limiting factors from the production and refinery sides. We are operating at high levels of demand partly because of the economic growth and increased dependence on oil in countries such as China and India. Their massive populations (1.3 billion and 1.17 billion respectively) and exploding middle classes have seen a move toward vehicle ownership and this has helped make oil even more important in their nations (World Bank, 2011). The increase in global demand is represented in Figure 3, Historical Oil Consumption by Region (BP Statistical Review of World Energy, June 2011). And specifically there have been major increases in the Asia-Pacific region. The United States, obviously, is not operating in a bubble. Increases in demand around the world can have major implications in the domestic American market. And because we have seen a tightening in the margin between Demand and Supply, there is a greater chance that the supply at certain points will not be able to meet the demand. This is characterized in the Queuing Theory as the arrivals wait time increases as more and more of the processing system is utilized. However, this rate of increase does not move linearly as you might expect or even move in correlation to the increase in demand. This wait time will increase exponentially as more of the system is utilized. The wait time of various systems that utilize the Queuing Theory for projections can be connected to the energy market and, in particular, the oil market. The oil market was selected because of the ease in which consumers can see the effects of the daily settlement prices at their local gas stations. This connection between how a bank judges how many windows to keep open can be extended to how much oil needs to be pumped out of the ground, as well as how many refineries need to be active to handle demand appropriately. Therefore, there are multiple steps that can be taken to adjust our current system to amend for increased oil demand, limited refinery capacity and increased production.

FIGURE 3: Historical Oil Consumption by Region



The Queuing Theory has an increased relevance to how our energy markets are moving and reacting to environmental stimuli. Over the last 20 years, the world has experienced a much higher demand for oil as it is an easy and accessible energy source to use in cars, trucks and boats. This demand is referenced in the system as the arrivals to process. Supply has also been a major issue and has two parts that constitute the processing portion of the system. These two parts include the production of oil and the refinery capacity. These elements work in conjunction to create the world oil market. There is such a high correlation between the waiting time in the Queuing Theory and the price of oil markets, because it is more common than expected to see jumps in waiting times and in the price of oil. This is characterized by fatter tails in the distribution and is likely caused by an exponentially increasing value of oil when there are adjustments to the demand and supply when operating at such high levels. Our current system is experiencing an increase in demand that is outpacing the current increase in refinery capacity or production. This means that instead of taking steps to improve the system, many politicians and consumers are "kicking the can down the road" in hopes that another solution will come along without their having to deal with the problem directly. Operation at such a high threshold will likely mean that shocks in the oil markets will be of a higher frequency as well as of greater magnitude.

GETTING BACK ON TRACK

The first step to adjusting the course that our world energy system is headed to is to lower the future expected demand for oil. Worldwide demand for oil is expected to rise to 92.9 million barrels per day in the next four years, according to the Organization of Petroleum Exporting Countries (Isidore, 2011). One way to help reduce this amount is to encourage domestic car makers to increase their average miles per gallon. This can be done by providing more tax breaks to car manufacturers that meet these requirements or it can be done by more forceful acts by Congress to "encourage" car companies to do so under penalty of the law. Another major role that the government in the United States can take is to encourage conservation. The government can provide tips on how to conserve gas, and local governments can expand the use of commuter lanes. These steps can encourage individuals to realize alternate benefits other than just reducing their carbon footprint. Lastly, if these steps are not effective, a much higher gas price will lead the push toward alternative fuels or conservation. This was seen in 2008 as gas prices at the pump were well over $4 in areas around the United States. As a result, the natural gas (substitute in some areas for oil) company that I worked for at the time saw a major increase in sales as the population shifted toward alternate sources of energy. This potential reduction in demand helped to ease the pain of high gas prices as oil producing nations were forced to increase their output to meet the extra demand.

Besides curbing demand, oil companies can take steps to increase refinery capacity. This will not happen unless a considerable amount of red tape in the governmental bureaucratic system is overcome. The fact that a new refinery has not been built in the U.S. since 1976 cannot be put solely on the shoulders of the oil companies. And while environmental groups have obvious concerns that lead them to oppose new refineries, a multi-pronged attack is needed in order to solve our energy problems. We all would like to use a type of energy that emits no CO_2 gases, does not pollute the water and costs very little. However, we cannot have our cake and eat it too, so to speak. If we need energy in our everyday lives, from heating our homes to driving to work, a feasible source of energy is necessary. Currently 8% of the U.S. total energy use comes from renewable sources of energy. Of this amount, only 1% comes from solar power and 8% from wind power (0.08% and 0.64% of total consumption, respectively) (EIA, 2011). While a comprehensive roadmap can include some of these elements, these sources of energy will not have a significant impact on the current energy system. Thus, we have to take the good with the bad and accept that in order to use energy we have to enable refineries to produce that energy.

The last area of concern relating to reducing the effect of backups in the worldwide energy system is to increase production of oil. OPEC figures that "According to current estimates, more than 80% of the world's proven oil reserves are located in OPEC Member Countries, with the bulk of OPEC oil reserves in the Middle East, amounting to 65% of the OPEC total." This results in "OPEC's proven oil reserves currently stand(ing) at well above 1,190 billion barrels (OPEC 2011)." This means that this organization has huge influence in how the supply of oil in the world will play out. OPEC commonly sets guidelines for how much oil each country will be allowed to pump per day. Whether or not it is the correct strategy, OPEC is likely to be blamed or congratulated for the current prices of oil. If OPEC would like to see higher prices, it can easily pull back the amount that the member countries produce and if it wants to drum up demand, it can easily increase the supply. Thus decreasing demand and increasing refinery capacity can have little effect if the cartel (OPEC) decides that it wants prices higher and it wants to pump less oil out of the ground. This creates a lot of problems politically for the United States as a major importer of international oil. As long as that remains true, OPEC nations will continue to have power or can at least keep America on its heels during discussions.

In the U.S. there are also steps that can be taken to increase production of oil. New methods are being used to get more oil out of each well. With advances in technology, companies are now able to drill to deeper depths in the ocean, as well as drill horizontally to get to hard-to-reach areas in the earth's surface. Typically recovery rates are about 20% for the amount of oil that can be retrieved from each well, so a small increase can have a major effect on available oil reserves. With these new techniques, there is a possibility that reserves in the U.S. could increase, assuming that deep water drilling is allowed to continue in the Gulf of Mexico. Increasing domestic reserves in the U.S. increasingly means moving toward offshore locations, specifically into deeper depths in the Gulf of Mexico to find and produce more oil. It is understandable that the US is hesitant to open up deep water drilling operations in the Gulf because of the recent BP disaster, but the overall consequences will be much worse if drilling is not allowed to resume to full capacity. For one, this increases the U.S. dependence on foreign oil as well requiring diplomatic strings to be pulled to have this flow uninhibited. Besides an increase to the overall supply of the oil market, drilling would also have a positive effect on the job market around the Gulf. That is why it is important to consider the overall system when making decisions regarding energy strategies that might otherwise be short-sighted.

PAX OR NOX U.S.?

Michael Santoro points out in his book, *China 2020*, that there are two paths toward which China can to move, Pax and Nox China (Santoro, 2009). The Pax China, as Mr. Santoro explains, is a positive view on how the current policies will affect China's future. The Nox version is a much dimmer viewpoint of its future. A similar dynamic can be seen with the United States and the effect of energy policies. Two distinct scenarios can have a direct impact on the U.S. over the next 20 years. In the best case scenario, politicians tackle the energy issue aggressively and take a multipronged attack with conservation, alternative fuels and building more facilities for current technologies. By taking these steps now, the country avoids major problems down the road. Thus, in the "PAX USA", changes establish a solid foundation for future generations. Over the next ten years, the United States and its European Allies create better supply lines, increase drilling and working on conservation efforts as well as developing alternative energy sources.

Under the worst case scenario, "NOX USA," multiple minor disruptions in the supply of energy will lead to high prices and civil unrest in Europe. These disruptions will help to break up the European Union as nations struggle with debt problems and, even worse, have problems keeping the lights on. The civil unrest will lead to the destruction of several pipelines in Eastern Europe and lead to significant supply problems. Gas prices in the United States will double, seemingly overnight. People will line up for miles like they did in the 1970's as they search for rationed oil.

It is true that while it seems unlikely that either of these ends of the spectrum will take place, it is important to think about what would happen if we simply did nothing and followed the status quo for energy policy. Energy has a major effect on our lives from the food we eat to the cars we drive. Having relatively inexpensive access to energy sources enables us to be able to afford the food that is delivered to the grocery store as well as to afford the gas to drive there. Oil markets can have an effect on every facet of our economy as well as the international relationships between the U.S. and various Middle East countries. It is difficult for politicians to discuss or deal with any situation unless there is a crisis. In 2008, there was a sudden increase in the price of oil. The result was that the presidential candidates were forced to address the issue. However, once the issue subsided and oil prices dropped, the conversation on energy was put to the backburner. Once again we are seeing the price of oil creep above $100 and any minor disruption can cause another huge price increase. By creating a comprehensive strategy now, the United States can avoid even worse problems in years to come.

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