Supply and Demand Dynamics of the Oil Market: A System Dynamics Approach

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Abstract. In this paper, we propose a revised model of the global oil supply and demand based on the system dynamics methodology. We investigate the effects of unconventional variables on the oil price, many of which are generally ignored in the traditional oil market models. These variables are the expectational variables that are formed based on the expected trends of the major determinants of the market. We model the oil price to follow the expected global oil supply to demand ratio, instead of their actual values. That is, based on the events that happens on either side of the market, whether or not the supply or demand, the influences of the events are quantified and subsequently, the related variables are initialized with proper values. That in turn affects the expected trend of supply or demand, which forms the oil price eventually. For our simulations, we consider the events of the 2015 year and analyze the events occurred in the 2015 including the reports on the Chinese economic growth, the conflicts in the Middle-East region, the US oil supply changes and various other events which form our model. Our results prove the efficiency of our model in predicting the trends of the price, supply and demand.

1 Introduction

Oil price is the determinant factor of almost all economies. This is due to the fact that oil is the most utilized fossil fuel, fueling the heart of most economies with the energy released from its burning. Many projects in an energy-related company depend on the oil price. Even though there exists many models on the oil model, most of them still fail in the unexpected events of the market. The system dynamics methodology with its unique facilities, proves itself to be a very successful approach in modeling the market changes, particularly, for markets that the unconventional and behavioral factors can affect the market. Such factors often are ignored in the purely economic models that base their formulas and reasonings purely on the data of the major factors [1–6]. Even models that are built purely based on the techniques from stochastic analysis fail to predict the oil price in the situation of events that cause huge changes in the price, which re referred to as the unexpected shocks [7–10].

In this paper, we provide a model of the oil supply and demand based on the system dynamics methodology. Like our previous works, [11–21] in this model, the expected global oil demand and supply values affect the global oil price. The expected variables are the adjusted values of the actual oil demand and oil supply using the predicted trends of the oil price for a near future time interval. Therefore, we have created a set of loops on the qualitative parameters whose cumulative effect is forming such expectations on the oil supply and oil demand. The values of those variables are dynamically determined using the trends of the underlying market factors as well as the qualitative data on the market, such as events of the Middle-East, a report on the Chinese stock markets, a report on the OPEC's decisions or reports of the world bank on various predictive variables. Moreover, the expectational variables range between zero and two with values closer to one. As a result, when the expectation on the global oil demand is multiplied to the global oil demand, the expected global oil demand is formed, which adjusts the value of the oil demand according to the slight change that is predicted. This has the benefit that, it causes the price to react instantaneously to the changes of the oil demand and price, as if those changes have already happened.

In the next section, we provide a shot background on the system dynamics approach, and explain the model and its loops. In section 3, we provide our simulation results, and lastly in section 4, we conclude our paper along with remarks on the future work.

2 Model

In this section, first, we provide a brief background on the system dynamics methodology, then, we provide our model, along with the causal loops. For simplicity, we only discuss the main loops of the model in here.

System dynamics modeling: Based on the system dynamics methodology, [22–24], first, we derive the main factors and parameters involved in the model through a detailed literature review on the related material. Then, we build a causal model that connect the variables to each other using the relationships that are derived. Then, the mathematical relations between each two variable that are connected through a causal line are developed. These relations are derived based on the available real data of the major variables, utilizing either time-series analysis methods, or regression analysis methods. On top of the built causal model, a stock and flow diagram is constructed, where the stock variables are calculated through integration of their flow variables with respect to time. The stock variables are representative of the variables whose values do nor change spontaneously to the level that are imposed by the external factors. Rather, the value of a stock variable has a memory (the initial value) and it changes with a momentum with respect to time accumulating values over time. On the other hand, the flow rate of an stock variable is the variable that controls the stock variable over the course of time, and its value can be affected momentarily to the desired level through the external variables that the variable depends on.

Strategies on solution of the model: Generally, the overall model reduces to a first order differential equation in terms of different variables. The core structure of the model consists of pure mathematical relations between well-established basic variables (obtained through data analysis on the past time series expressed as autoregressive models). Then, in order to model the effects of the outlier data, the corresponding parameters and variables are trained according to the data of related past occurrence of events. These variables are generally triggered with initial value variables when their effects are to be analyzed in the overall model. In order to solve the model, a numerical method such as Runge-Kutta is used to numerically solve the differential equations [25].

Main oil loop: The main loop of the oil market is depicted in Fig. 1. The global oil price, the expected global oil demand, and the expected global oil supply are the three main stock variables of the model. The oil price is changed only through the expected oil demand and the expected oil supply using their ratio. The relationship between the oil price change rate and the ratio, along with the reverse relationships between the supply change rate and demand change rate with the price are determined through regression analysis on the historic data of price, supply and demand. Likewise any other free market, on a normal condition of the market, an increase in the oil price causes the global oil demand to decrease, which increases the supply to demand ratio. As a result, the oil price reduces slightly to adjust to the decreased ratio, reaching to a balance. On the other hand, an increase in the price, causes the oil demand to decrease and subsequently to increase the supply to demand ratio. Note that due to the elasticity of the demand and supply, the changes in the demand and supply do not occur incidentally, whereas the changes in the price can occur momentarily as a response to an event that occurs on either demand or supply side, even before the real supply or demand changes [26].

Demand loops: We have divided the oil demand into the demand of OECD countries and Brazil, Russia, India, China, East Asia (other than China) and other countries based on their relatively similar change rates of the oil demand, and other factors such as economic growth, population growth rate and educated population growth rate. With an increase in the oil price, the economic growth on either sides is negatively impacted. Such a change mainly depends on the oil-dependency of the country [27]. In the developing countries, the oil dependency is relatively higher than western countries [28]. This is due to the fact that generally in the developing countries, fossil fuels provide the easiest way of economic development, and higher technologies which reduce the oil consumption are not readily available in the developing countries. As mentioned before, during normal operations of the market, an increase in the oil price causes a decrease in the oil demand which is elastic. Such an elasticity of the oil demand can be explained through economic mechanisms that should all change with enough time delays before a change in the oil demand occurs. One of these variables is the economic growth calculated as the annual GDP growth [29]. In our model,

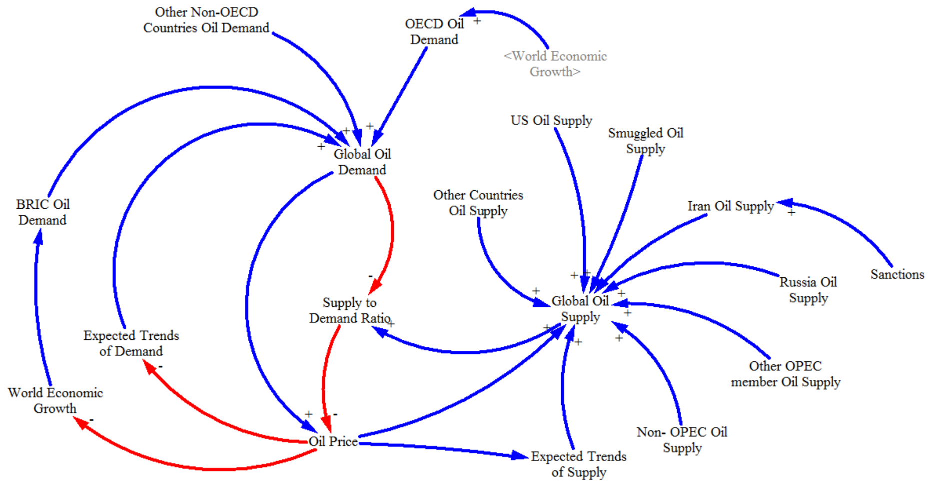

Fig. 1. Oil price main loop.

the relations between the economic growths of the above-mentioned categories of demand (calculated as the weighted average according to the oil demands of the participating countries in a group) and their average demand is calculated based on the Least Absolute Deviation (LAD) regression analysis which is more robust to the outliers than a simple regression analysis [30].

Supply loops: As shown in Fig. 1 the supply loop's main variable is the expected global oil supply. The underlying global oil supply consists of the OPEC, US, Iran, Russia, Saudi Arabia, the other non-OPEC countries, and the other OPEC countries supply along with the smuggled oil. We have considered Iran's supply separately, since Iran's supply has not followed a consistent change rate during the past years due to the intense sanctions on Iran's economy and particularly, Iran's oil sector after 2012 [31]. Most of these sanctions have been removed after an agreement between Iran and P5+1 countries including the US, the UK, France, China, Russia, (which are the permanent members of the United Nation's security council with a veto right) and Germany. The Joint Comprehensive Plan of Actions called the JCPOA was established in 2015 and implemented in 2016 [32]. After the JCPOA, Iran's oil exports (and overall production), which was reduced largely after the 2012 sanctions, started to increase and the latest reports the International Energy Agency (IEA) shows that during the mid-2016, Iran's production has recovered considerably [33].

On the other hand, we have modeled the Saudi Arabia's oil supply, which is part of the OPEC supply likewise Iran, separately. This is also due to the observation that during the recent few years, particularly after 2013, their oil production has sometimes exceeded the predicted values of the OPEC, which makes us to model their production separately [34]. In fact, one can argue that other than a few exceptions, all of the countries of the OPEC have mainly acted independently according to their individual benefits rather than the cumulative benefit of the OPEC, particularly after the extreme descent in the prices during 2014 [35]. Therefore, one can argue that the OPEC has lost its performance, efficiency and proficiency to a considerable amount with respect to the initial years of the OPEC. for instance, after the large decrease in the oil price in 2014, it was expected that the OPEC would chose to lower down their production rate as a response, which never happened (at least until 2016) [36]. This was mainly due to the fact that the Saudis argued that it is the US supply that is responsible for the supply surplus in the market, and if they chose to decrease their production, the US shale oil producers would take the market share of the Saudis [37]. Therefore, strategically they chose to keep their production at a high level to force the prices even further down so that the US producers would go out of business. This strategy in fact has not proved itself to be as efficient as efficient as the Saudis would have predicted. The main reason is that the market data shows that even though two years have past such a decision, the US production has not decreased as the expectations (nonetheless the slight decrease in 2016) [37]. Therefore, even in 2016, the market still faces a huge surplus in the supply, which is exacerbated by knowing the fact that in the oil market the marginal surplus of one million barrels per day can shake the prices [34].

The US oil supply has increased considerably during the past decade, due to the developed technologies that made the extraction of the shale oil cheaper than before. During the 2015, many US-based oil companies have faced tough financial time, but mostly have survived with low margins of profits. The major loss has been felt by the upstream industry which are mainly responsible for the Exploration and Production (E&P) [38]. However, the downstream industries which consists of the refineries and companies that process the natural gas, as well as distributing the products from crude oil and gas have shown the least loss. Proportionate to their portfolio of final deliveries, the midstream companies have suffered in the middle. As a result, small businesses whose major job was dependent on the exploration of the horizontal wells have suffered the most, and leaving the business in some cases. Nevertheless, as mentioned, the US still produces a large amount of oil and the growth in the US production has gone negative only after Apr. 2015, staying more steady till the end of 2015 and going negative again after 2016. However, it is predicted that the US producers will recover in a near future, and the energy prices shall remain low for a mid-run. This is mainly due to the consistent research that has lowered the break-even price of the oil production from unconventional resources, which is expected to keep its trend [39–41].

The Russian oil supply is considered separately due to the sanctions which have caused troubles in Russia's oil-dependent (and gas-exports-dependent) economy [42]. Even though the sanctions might be removed in the near future, which would help the Russian producers to recover from their sanctioned period. The other non-OPEC countries act more individually in their policies, but more often on a consistent basis and that is why we have also allocated a variable for those countries cumulatively. The smuggled oil refers to the unofficial oil that is produced and sold through unofficial and illegal channels, and their benefits often transfer to the non-governmental organizations [43]. Particularly, their money funds the malicious militia groups that are involved in wars in regions such as Syria [44]. The smuggled oil's existence and value depends on the existence and intensity of the political conflicts in the corresponding countries.

3 Simulation Results

In this section, we provide our simulation results to support our model. First, we provide simulation results. In the simulation scenario, we train our model to reproduce the trends for the historic changes of the oil price, supply, and demand price for the year of 2015. We use the WTI oil price data from [45], oil demand data from [46], oil supply data from [47], and economic growth data from [48].

Simulation vs. the real oil price data in 2015: Figure 5 shows the simulation results vs. the real data of the oil price on a daily basis for the 2015 year. As it is seen in this figure, the oil price starts from a relatively low value of 53.45 USD in the beginning of the year, and reaches to 37.13 USD at the end of the year. The simulated oil price also starts from the same value as the actual data, and reaches to 38.08 USD at the lat quarter. Therefore, our model successfully reproduces the trends of the oil price for a time interval of one year.

Simulation vs. the real oil supply data in 2015: Figure 3 shows the quarterly data of the oil supply for our simulations depicted vs. the real data for the 2015 year. As it is seen in this figure, the oil supply has increased during 2015, even though the price has decreased. This is consistent with our observations on the strategies of the individual producers. Once again, as depicted, our model successfully predicts the trends of the supply changes in 2015.

Simulation vs. the real oil demand data in 2015: We have used the IAEs reports to obtain the quarterly data of the global oil demand. Figure 2 depicted the simulation results of the global oil demand vs. the real data in 2015. As it is depicted in this figure, we have shown the average value of demand for each quarter from our daily simulated data. This figure shows that the oil demand has increased slightly during the 2015, and our results are consistent with the data.

Simulation vs. the real oil supply to demand ratio in 2015: Lastly, we have depicted the ratio of supply to demand on 2015 for both the real data and our simulated data in Fig. 4. This figure shows that there is a surplus of oil during the entire year of 2015, which provides the main reason of the falling prices. Although towards the middle of 2015, the prices slightly recover due to various reasons such as optimism in the market, the supply surplus did not let the prices to recover and they continue to fall by the end of 2015.

4 Conclusion and Future Work

In this paper, we provided a revised model of oil market to investigate the supply and demand mechanisms. We built our model based on the system dynamics methodology where the casual loops are built upon the parameters ex-

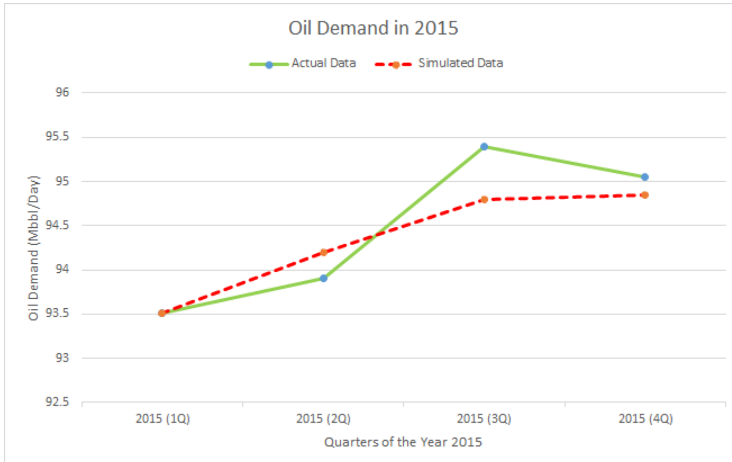

Fig. 2. The simulated vs. real data of the oil demand during 2015.

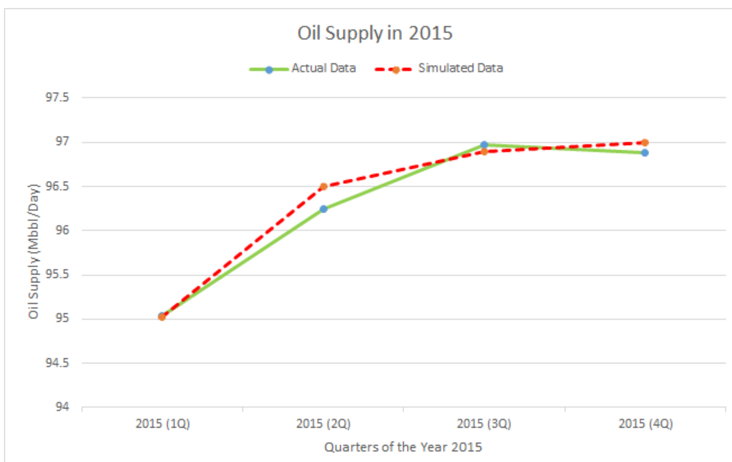

Fig. 3. The simulated vs. real data of the oil supply during 2015.

tracted through literature analysis. The overall model is reduced to a system of ordinary differential equations on a stock and flow model. We modeled the oil price to change based on the expected global oil supply to demand ratio. In our model, the expected trends of the expectational variables are determined through the anticipated changes of the supply and demand and the events which are important in forming the supply and demand values. The model is trained using the real data and simulated for the 2015 year. Our simulations prove the performance of our model. In our future work, we will provide more analysis on the historic data, and will investigate the effects of more parameters.

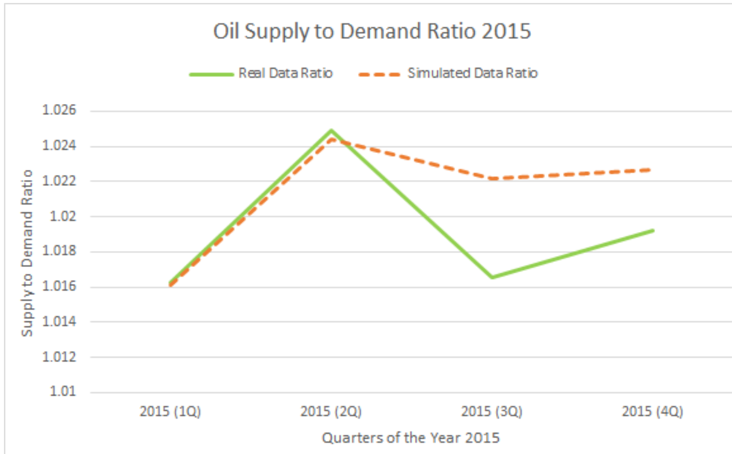

Fig. 4. The simulated vs. real data of the supply to demand ration of global oil during 2015.

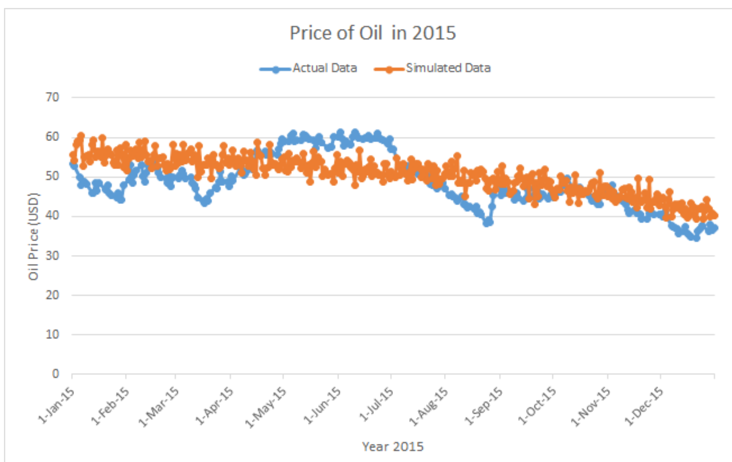

Fig. 5. The simulated vs. real data of global oil price during 2015.

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