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ENERGY POLICY AND OIL PRICES: SYSTEM DYNAMICS APPROACH TO MODELING OIL MARKET

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The pattern of global oil demand, real oil price, and world economy in the future is studied through system dynamics modeling. Based on the simulation, the oil demand will drop and then gradually recover while the real oil price will be stable and then drop mimicking a sigmoid curve. The economy will continuously increase. If an economic stimulus policy is implemented, the oil demand is expected to have a shallower drop. Thus, the real oil price is likely to be an S-shaped curve with a higher value, and the economy is expected to grow faster as compared to the case when there is no stimulus policy.

Introduction

The oil market has gone through a number of structural changes in the last five decades. In the 1960s the focus was on the role of large multinational oil companies and their control of the market both physically and politically. In the 1970s the focus shifted to the role of OPEC in managing the oil market. The initial scholarly research discussion was focused on the political economy of oil (Sampson 1975). The 1980s saw the emergence of the oil derivative market and its impact on the structure of oil trading. The new instruments in the oil market, particularly oil futures and options market for oil, changed the structure of the market and trading practices. The oil futures and oil options shifted the balance of control of the oil market from OPEC and Oil companies to Wall Street and investment firms. This increased the speculative pressure on oil prices (Razavi and Fesharaki 1991).

The market was relatively balanced in the 1990s, with the exception of political factors caused by war in Iraq. Iraq's invasion of Kuwait in 1990 created serious political risk in the international oil market. This in turn resulted in a sharp increase in the oil prices during that conflict. Once the political risk premium disappeared, oil prices reverted to their equilibrium level.

Based on the policies that are currently being discussed and implemented, we believe that the next decade will be all about energy and oil conservation. The current US administration is focusing on the production of green and renewable energy. If successful, this will impact the oil market in the direction of maintaining balance between supply and demand.

Oil and energy modelers have taken different approaches. One group of researchers has focused on the estimation of the price elasticity and income elasticity of oil demand. Notable among this group is the work of Morris Adelman (1982) which claimed that there would be a decline in the coefficient of demand relative to economic growth in the 1980s as a result of price increases. The International Energy agency has also developed a complex econometric model for oil market demand forecast. Other organizations such as the OECD and the World Bank also have developed oil market forecast models based on detailed time series structures.

The second type of oil models are based on the path braking work of Hotelling (1931). These types of models argue that the price of exhaustible resources must be set at the opportunity cost of its replacement. The Hotelling theory received considerable discussion through the 1970s as an explanation and justification for oil price increases (Heal and Chichilnisky 1991).

The other cluster of oil market models were based on a system dynamic approach to modeling. One of the earlier works was the Club of Rome study which focused on the issue of exhaustibility of oil and other natural resources. This was a variation of Hotelling's work. While Hotelling focused on the price of exhaustible resources, the Club of Rome model focused on the potential of exhaustibility of resources and a doomsday. This scenario was partly supported by the 1973 oil price increase. However, critics of historical extrapolation based on path dependency argued that there would be negative feedbacks that would modulate demand once price is sufficiently high. These feedbacks would be in the form of a technological component, conservation, and the emergence of alternative energy.

John Sterman built a system dynamic model for the oil market as part of his doctoral research (Sterman 1981). The most extensive approach to oil market modeling using a system approach was undertaken by the International Institute for Applied Systems Analysis (www.iiasa.ac.at). Besides Sterman's dissertation, there are a number of researches that simulate energy market by using system dynamics approach. To be specific on oil price and oil market, Choucri (1981), Greenman (1994) and Mashayekhi (2001) developed the model to explain the fluctuation of the oil price based on the global oil demand and supply. They treat the oil producers, mainly OPEC producers, as active players who can manipulate the oil demand and supply. However, this paper takes a different approach by perceiving the OPEC producers as passive players.

In this paper we created a hybrid system dynamic model of the international oil market. The model treats OPEC as a residual producer of oil with its demand being determined by world oil demand and non-OPEC oil production. The OPEC capacity and demand for its oil will determine its flexibility to manage the market and oil prices (Razavi and Samii 1983). The model considers that the increase in price has a positive impact on energy conservation and oil exploration leading to additional non-OPEC supplies. The dynamic of price changes on oil demand and non-OPEC supply changes are modeled in this paper using Vensim.

Policies that help accelerate conservation and promote oil exploration will result in huge oil prices in the future. The model will simulate various policies and their impact on each component of the oil model.

Energy Policy and Oil Price Model

In this study, we model the effect of energy policies on the market oil price. This model considers the interaction among the following factors: oil demand, supply by OPEC and non-OPEC producers, oil price, economic growth, energy conservation, the development of new oil fields, and alternative energy as shown in Figure 1. From Figure 1, we observe that the increase in real oil price will reduce the economic growth, which in turn will reduce the oil demand, and increase the amount of energy conservation as well as the development of alternative energy, which also reduces the oil demand. An increase in real oil price also stimulates new oil field exploration which will increase the supply capacity of non-OPEC producers. The difference between oil demand and the supply from non-OPEC producers is the demand for OPEC oil which will affect the real oil price.

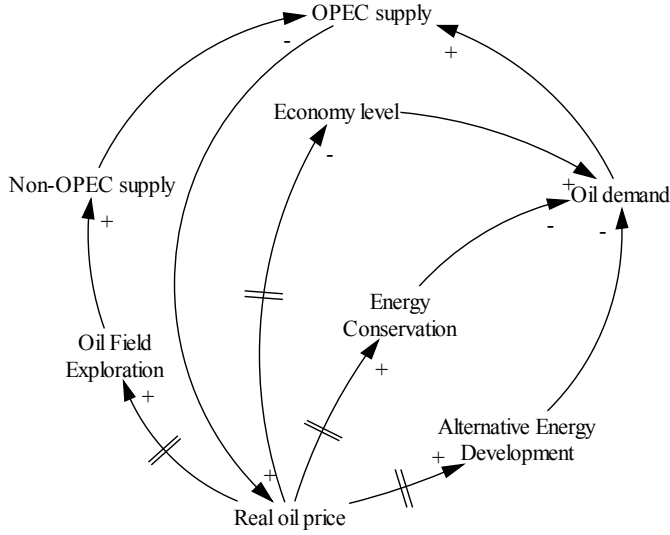


Figure 1: The interaction between each factor

To simplify the model, we separate the whole model into 4 modules: Demand for OPEC oil, Oil price and economic growth, Oil price and energy conservation, and Oil price and the development of new oil fields and alternative energy.

The first module is the oil demand for OPEC. This module reproduces the interaction between oil demand, non-OPEC oil supply, OPEC oil supply and the oil price. We assume that OPEC is a passive producer and produces based on the demand that is not fulfilled by the non-OPEC producers. Therefore, OPEC supply is equal to the difference between oil demand and non-OPEC supply.

$$OS_t = D_t - NOS_t \quad (1)$$

Given D_t is the oil demand at time t ; OS_t is the required OPEC supply at time t ; and NOS_t is the non-OPEC supply at time t .

OPEC's capacity utilization ratio which is the ratio between OPEC's supply and OPEC's capacity will affect the oil price. If the OPEC capacity utilization ratio is over the range of price stability, the price will increase exponentially.

$$CUR_t = OS_t / OC_t \quad (2)$$

$$\Delta P_t / P_t = f(CUR_t) \quad (3)$$

If $CUR_t > 0.8$, $\Delta P_t > 0$; Price increase

If $0.5 \leq CUR_t \leq 0.8$, $\Delta P_t = 0$; Stable price

If $CUR_t < 0.5$, $\Delta P_t < 0$; Price collapse

Where CUR_t denotes the OPEC capacity utilization ratio at time t ; OC_t is OPEC's production capacity at time t ; P_t is the oil price at time t ; and ΔP_t denotes the change in oil price at time t . The 0.5 and 0.8 boundary is based on historical information. In the 1980s when OPEC's production fell to around 15 million barrels per day, less than 50% of OPEC's capacity, the oil price collapsed. In the 1970s and 2008 when demand approached OPEC's capacity, the price began to rise.

The second module is the oil price and economic growth. This module replicates the interaction among oil price, economic growth, and change in oil demand from economic growth. First, the oil price affects the economic growth which also affects to the growth of oil demand that based on the economic level.

$$\Delta Y_t / Y_t = \Delta P_t / P_t \times EYP \quad (4)$$

$$DE_t = \Delta Y_t / Y_t \times EDEY \quad (5)$$

Where Y_t is the GDP which represent the economic level; EYP is the elasticity between oil price and GDP; DE_t is the oil demand change from economic growth at time t ; and EDEY is the elasticity between GDP and oil demand

Clearly, economic growth is impacted by a number of different factors such as business cycles and government policies. However, historically oil price change has had an impact on the global economy. The oil price increase of 1973, 1980, and 2008 each was followed by a global economy recession.

The third module is the oil price and energy conservation. This module simulates the interaction between the oil price and the oil demand reduction from energy conservation. The change of energy conservation is based on the ratio of the current oil price and the normal oil price, which is the median of the historical price.

$$NP = \text{median}(\text{historical } P) \quad (6)$$

$$PNR_t = P_t/NP \quad (7)$$

$$EC_t = f(PNR_t) \quad (8)$$

Where NP is the normal oil price; PNR_t is the oil price to normal oil price ratio at time t; and EC_t is the oil demand change from the energy conservation at time t. The interesting issue to consider is the reaction time it takes for energy conservation to respond to oil price. This represents the behavioral aspect of the model. Such behavioral aspect could be faster in the form of energy conservation at the household and industry levels. However, technology-based energy conservation may take longer time. Technology development and new important commercialization of technology may take time before the impact is felt on the oil market.

The last module is the oil price and the development of new oil field and alternative energy. This module reproduces the interaction between oil price, new oil field development, alternative energy, non-OPEC supply, and oil demand. The development of new oil fields and alternative energy are also affected by the oil price to normal oil price ratio. New oil fields will increase the non-OPEC supply while the alternative energy will reduce the oil demand.

$$NOF_t = f(PNR_t) \quad (9)$$

$$NOS_t = NOS_0 + \int NOF_t dt \quad (10)$$

$$AE_t = f(PNR_t) \quad (11)$$

$$D_t = D_0 + \int (DE_t + EC_t + AE_t) dt \quad (12)$$

Where NOF_t is the supply from new oil field development at time t; NOS_0 is the non-OPEC supply at the start of the simulation; $\int NOF_t dt$ is the integration of the supply from new oil field development over the simulation time; and AE_t is the change in oil demand from alternative energy at time t. These two factors are relatively sensitive to the price and price fluctuation. Price fluctuation reflects risk for investors. Both new oil field development and alternative source of energy would require considerable investment. Capital investment would require stable and increasing prices to assure adequate rate of return and to make it financially attractive.

Model validation

This model is validated using 2 methods which are parameter validation and overall model validation. The parameter validation is used to obtain the values for the parameters by using an empirical data. The overall model validation is the comparison of the simulation results to the actual data over a period of time.

Parameter validation

We validate 3 parameters in this model which are the effect of the OPEC capacity utilization ratio and the real oil price change, the elasticity between oil price change and the economic growth, and the elasticity between the economic growth and the oil demand.

First is the effect of OPEC's capacity utilization ratio and the percentage of the real oil price change. The OPEC production rate and the oil price were collected from the OPEC Annual Statistic Bulletin. We mapped the data of the OPEC Capacity Utilization ratio which is the ratio between OPEC's production and OPEC's capacity and the change of oil price in real terms which is adjusted by inflation from 1983 to 2008 as shown in the Figure 2. We assume the OPEC production capacity is constant at 34 million barrels per day.

From the graph, we observe that it can be divided into 3 areas based on the characteristic of the real oil price change. The area in the middle is the price stability area which goes from 50% of the OPEC Capacity Utilization ratio to 80% of the OPEC Capacity Utilization ratio. The area on the right is when the OPEC Capacity Utilization ratio is higher than 80% which shows an increase in oil price. On the other end, the price decreases when the OPEC Capacity Utilization ratio is lower than 50%.

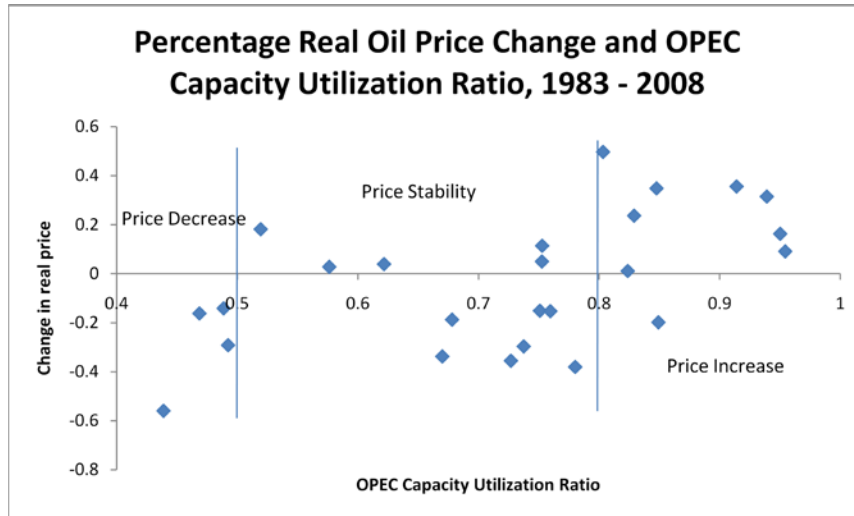


Figure 2: Percentage Real Oil Price Change and OPEC Capacity Utilization Ratio

Next is the elasticity between the oil price and the GDP. We use a regression model between the percentage change of real GDP and the percentage change of real oil price. The equation is;

$$(\Delta Y_t/Y_t) = \beta_0 + \beta_1(\Delta P_t/P_t) + \varepsilon_t \quad (13)$$

Due to the limited availability of the data on global real GDP, we used the real US GDP which was collected from the Organization for Economic Co-operation and Development (OECD). We used the data from 1983 to 2008. The results show that the model with a 2-year-lag provides the best fit. Therefore, the 2-year-lag will be incorporated in the model.

The regression result shown in Table 1 indicates that the constant coefficient is 2.8% and the coefficient of the change of oil price is -2.1%. Therefore, 2.8% will be incorporated in the model as the constant real GDP growth and -2.1% will be the elasticity between the real oil price and the GDP.

Next is the elasticity between the GDP and the oil demand. The regression model to examine the elasticity between the GDP and the oil demand is;

$$DE_t = \beta_0 + \beta_1(\Delta Y_t/Y_t) + \varepsilon_t \quad (14)$$

The data on global oil demand was collected from the Energy Information Administration and the data on Global real GDP was collected from the Economist Intelligence Unit. The data was collected from 1987 to 2007. The results shown in Table 1 indicate that the elasticity between the Global GDP and the world oil demand is 52.2%.

Table 1: Regression result for Equation 13 and 14

	Equation 13	Equation 14
Dependent Variable	$\Delta Y/Y$	DE
Independent Variable	$(\Delta P/P)(-2)$	$\Delta Y/Y$
b_0	0.0279***	-2.93×10^{-3}
b_1	-0.0210**	0.522***
R^2	0.2131	0.3478

Remark: *P<0.05; **P<0.02; ***P<0.01; one-tailed

Overall model validation

In addition to obtaining sound parameter values from the parameter validation method, we also compared the simulation results with historical data. We checked on three variables which are real oil price, oil demand, and supply from non-OPEC producers. We compared the simulation with the historical data from 2000 to 2008. We choose to compare the data since 2000 because it is the initial year of simulation and the most up-to-date data we have are for 2008.

The results shown in Table 2 prove that the model can represent the actual situation which is identified by the high R-Square in global oil demand and supply from non-OPEC producers and medium R-Square in real oil price. The R-Square of real oil price is lower than others because we do not include speculation into the model.

Table 2: Fitness of the simulation to the historical data

	R-Square
Real oil price	0.5558
World oil demand	0.8787
Supply from Non-OPEC producers	0.9824

Model Simulation

After the model is validated until the year 2008, we simulate the model starting from 2008 onward to observe the pattern of real oil price, global economy level, and the world oil demand in the future. The simulation is developed through the iterative calculation based on the previous values of each variable as indicated in equation 1 – 12. The results of global oil demand, real oil price, and world economy are presented in Figure 3.

Without government intervention and speculation, the global oil demand will drop continuously to a particular point. After that, the demand will pick up as an exponential curve as shown with the line number 1. For the real oil price, the price will be stable for a while and then the price will drop significantly and gradually become stable at the end of the simulation period as shown with the line number 2. The world economy as shown with line number 3 keeps increasing during the simulation time. This shows that the oil price does not have a significant effect on the world economy.

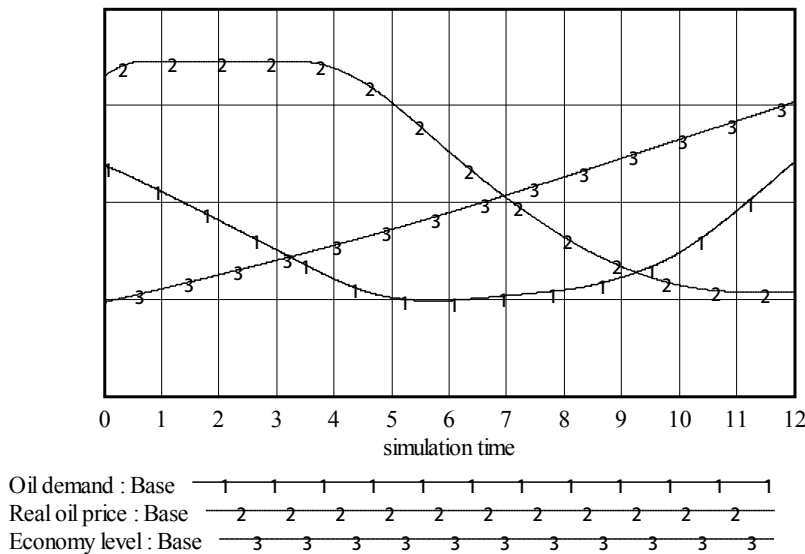


Figure 3: The pattern of global oil demand, real oil price, and world economy

Scenario Study

The previous simulation is based on the assumption that there is no government intervention and the global economy has a constant growth if the effect from oil price is not included. However, due to the current global economic crisis, some governments may provide an economic stimulus package which will stimulate economic

growth all over the world. We will simulate to examine the effect of an economic stimulus package on the global oil demand, real oil price, and the world economy.

We create two scenarios to compare with the base case which is the case without any economic stimulus package. “Light stimulus” is the scenario in which the economic growth increases by 2% and “Strong stimulus” is the case in which the economic growth increases by 4%. An increase in economic growth is implemented in the model through an increase in ΔY_t in the equation 4 and 5. The results are presented in Figure 4, Figure 5, and Figure 6.

The global economic level presented in Figure 4 shows the expected pattern. The scenario with a strong economy stimulus package has the highest economy level with the fastest economic growth.

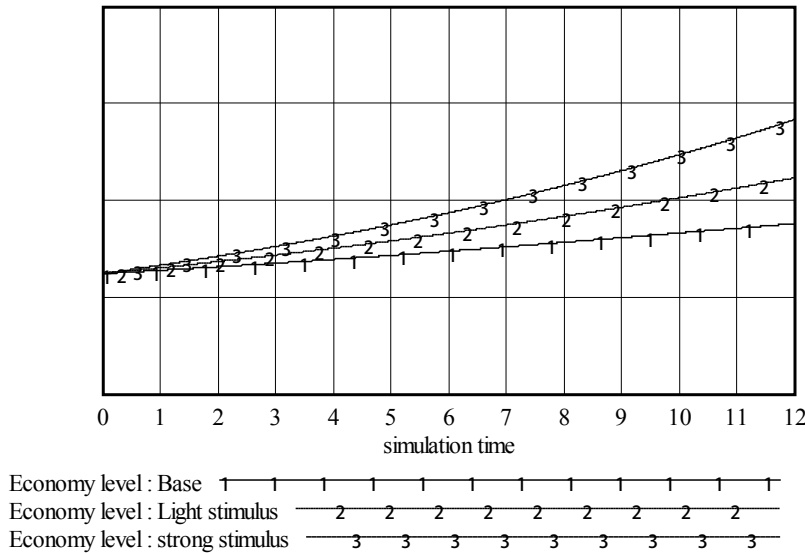


Figure 4: Economic level under different scenarios

The world oil demand in Figure 5 shows an interesting pattern. While the base case has a U-shape-like pattern, the cases with a “Light” and “Strong” stimulus package have a V-shape like pattern, drop at a lower rate but pick up at a higher growth rate. However, at the point when the demand has picked up, the case without the stimulus package has a jump in the growth rate and reaches almost the same level as the demand in the strong stimulus package case.

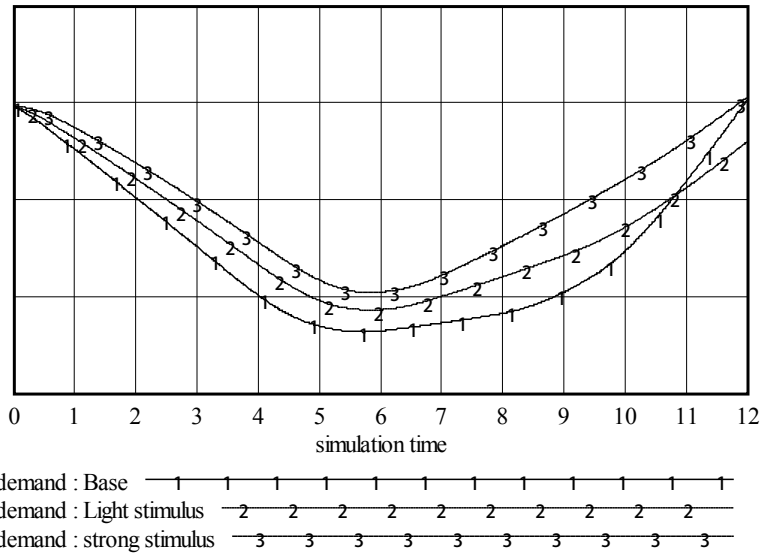


Figure 5: World oil demand under different scenarios

For the real oil price, the “Light stimulus” scenario and “Strong stimulus” scenario show that the real oil price will be higher than the base case and has the same pattern as a base case. The patterns on all cases are the same as shown in Figure 6. There could, of course, be another government stimulus package in form of fiscal and monetary policies that could impact the economic growth. Those stimuli are considered to be outside the boundary of our model and are assumed to be constant.

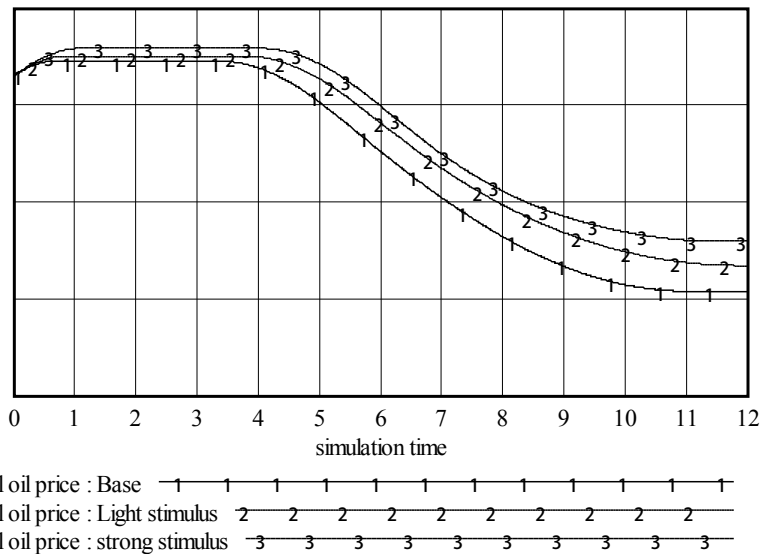


Figure 6: Real oil price under different scenarios

Conclusion

In this paper, we create a model to examine the pattern of real oil price and the economy by incorporating the interaction between real oil price, economic growth, energy conservation, alternative energy, new oil field

exploration, oil demand, and supply from OPEC and non-OPEC producers. The simulation from the model closely fits with the historical data.

In order to see the pattern of economic level, oil demand, and real oil price, we simulated the model after 2008 since that is when we have the most up-to-date data available. The economy keeps growing during the simulation period while the global oil demand shows a U-Shape-like pattern which drops during the early period and then picks up later. The real oil price stays constant at the high level for a period of time and then drops and stabilizes at the low level at the end of the simulation period. When considering all graphs together, the pattern of real oil price lags behind the pattern of oil demand for a period of time. Moreover, the real oil price does not have a significant effect on the world economy.

We also created a scenario to study the effect of an economy stimulus package on the economy, oil demand, and the real oil price. The economy level with the stimulus package grows faster than without the package. The oil demand in the case when there is a stimulus package can pick up faster than the one without the package. The oil price in the stimulus package case is higher than the one without the package but the pattern is the same.

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