CS426 Agent-based Modelling and Simulation
Final Report
Wei Jiaqi, Yang Fan

1. Introduction

A commodity market is a marketplace for people to trade raw or primary products such as lumber, gold, coal and crude oil. It could be either physical or online, and there are around 50 major commodity markets around the world, in which about 100 different kinds of primary products are traded daily. (Chen, 2020)

We are interested in this topic because everything we see and use around us is or is made of commodities. The price movement of the commodities tightly affects people's daily life and even living standards. We talk about prices every day, such as the prices of clothes, food and electricity, which are all directly or indirectly influenced by the moves of commodity markets. Therefore, we would like to explore more about the commodity market.

Agent-based modelling and simulation is a good idea in this case because it can better help us to understand the interactions between the multiple types of agents in the market and market environment. As each type of agents has their special rules or trading strategies, it is difficult and strenuous to carry out top-down analysis of the dynamic commodity trading process in the market. Therefore, agent-based modelling and simulation allows us to study the evolution of the market in an easier and clearer way based on various internal and external parameters of the model.

2. Literature Review

Players in the commodity market always try to predict prices or price change in the future. The ability to anticipate future price movement is important for sellers, buyers and other players in the market as they need the information to plan and decide what marketing strategies to use and how to manage risks. Currently, two main approaches are used to analyse commodity prices: fundamental analysis and technical analysis, which will be explained further below. (Mattos, 2014)

2.1 Fundamental Analysis

Fundamental analysis helps to predict the future prices by analysing how the supply and demand variables affect prices. It is called fundamental analysis because the key idea of this method is to learn about the fundamental forces of supply and demand and find out their impact on prices. In a crude oil market, some typical supply side forces could be crude oil production and imports and typical demand side forces could be oil consumption and exports. (Bajpai, 2020) The information about those supply side and demand side forces is collected during a specified period of time and combined to obtain the expected total supply and demand to calculate the forecasted price at the end of that period.

However, the fundamental analysis can only give us a generic view about prices over a long period of time. The supply and demand data collected and used for analysing is usually not updated in time for short run price analysis. (Mattos, 2014)

2.2 Technical Analysis

Technical analysis can instead provide a better view in forecasting price change in the short run. This method predicts future prices by finding and utilising patterns from the past price trend. There are many technical indicators to use in technical analysis such as Average Directional Index, MACD and Relative Strength Index. (Author, 2019)

There are two problems applying technical analysis. One problem is that sometimes the historical price trend may not have an obvious pattern, or the pattern identified may change due to exogenous factors. Another problem is that the analyst may face difficulty in deciding what parameters or indicators to use for analysis. (Mattos, 2014)

2.3 Agent-based Modelling and Simulation

Agent-based Modelling and Simulation can be used to predict prices in both short run and long run as it is logic based. It is also able to test the impact level of different parameters via experiment to help the analyst find out the key influential parameters.

3. Problem Statement

Our project will explore the roles of different players in the crude oil market as a single market and how their strategies and daily trading activities will affect and will be affected by the market environment variables. We hope that our project could discover and provide some new ideas and insights for people who are interested in commodity trading.

4. Model Description

Our model is a continuous double action model. Agents act in the single commodity market, buying and selling, determining the futures price. In this model transactions are processed one at a time by a mechanism known as continuous double auction, buyers and sellers place at any time their orders, specifying at what price they are willing to buy or sell.

4.1 Agents

Hedgers: Hedgers are commercial producers or consumers of a traded commodity. They are exposed to commodity price volatility in the spot market. They use the futures market to offset (hedge) this risk.

Speculators: Speculators may not have any exposure to the spot market. To them, commodity futures are an investment avenue, like the stock market. They can either trade with other speculators or trade with market makers. They have their own attributes such as buy, sell, get information, price ,cash, options and bankruptcy. If they are not bankrupt, they can choose to buy , sell or get information as their actions.

Market Makers: The market maker is a party that can buy or sell a large amount of asset at a publicly stated price in order to influence the liquidity of the market. The market maker's goal is to earn profits and to achieve buying low and selling high, so that the ask price always exceeds the bid price.

4.2 Exogenous Factors

Production: labour patterns, development in the tools and technologies used, etc.

Economic and political environment: trade constraints, subsidies, taxes, etc.

Natural factors: climatic conditions, crop diseases, earthquakes, etc.

Those factors are external factors which are uncontrollable and have certain probabilities to affect the spot price in the crude oil market. There is a correlation between the market spot price and the market futures price.

4.3 Sequence of Events

4.3.1 Setup

Firstly, it set futures price based on spot price and exogenous effect variable. The exogenous effect variable is derived from three factors which are production, policy and regulations and natural factor. The three factors have two attributes which are the probability of happening and the intensity level. The final combined effect of the three factors is calculated by the following steps.

Calculate the impact forces (F) from the intensity levels (L)

$$F_{production} = (-1/L^2_{production})$$

$$F_{policy} = 1 - \frac{1}{1 + e^{-L_{policy}}}$$

$$F_{natural} = 0.1 * L_{natural}$$

Add in the probability of happening

In order to use the probability of happening to calculate the weightage for each factor in the final exogenous variable, firstly we sum their probabilities (P) together, and then we divide the result of the summation by their individual probability to calculate the weightages (W).

$$W_{production} = \frac{P_{production}}{P_{production} + P_{policy} + P_{natural}}$$

$$W_{policy} = \frac{P_{policy}}{P_{production} + P_{policy} + P_{natural}}$$

$$W_{natural} = \frac{P_{natural}}{P_{production} + P_{policy} + P_{natural}}$$

Calculate the final exogenous factor (FE)

$$FE = W_{production} * F_{production} + W_{policy} * F_{policy} + W_{natural} * F_{natural}$$

The futures price is set by the following formula:

$$Futuresprice = Spotprice * \big(1 + N(0, FE)\big), where\ N\ is\ a\ normal\ distribution$$

Then, the model creates certain number of speculators and their initial cash is also set following a normal distribution.

Lastly, it creates one market maker and certain number of hedgers to participate in trading.

4.3.2 Go
Initialize

Set market maker ask price (AP) and bid price (BP):

$$AP_{market\ maker} = Futuresprice + \frac{Bid - ask\ spread\ price}{2}$$

$$BP_{market\ maker} = Futuresprice - \frac{Bid - ask\ spread\ price}{2}$$

The bid-ask spread price is the amount that the ask price exceeds the bid price. (Ganti, 2020) It is set by the analyst.

If speculators are not bankruptcy, the model will set some of the speculators' getting information status to true and others to false according to the speculator participation rate. For speculators who are not getting information, there is an equal probability that they are performing buying or selling action, and their trading price will follow a normal distribution. The colour of the buyers will be set to red and the colour of the seller will be set to green. Then the colour of the rest of the speculators who are getting information will be set to grey.

At the beginning, there are arbitrary initial speculation upper and bottom lines to prevent excessive volatility in the market. Starting from the second time step, the price limit becomes variable and is adjusted according to the final futures price at last time step. When futures price is greater than the initial upper line point or the variable upper line point, the model will set all speculators sell action. When futures price is less than the initial bottom line point or the variable bottom line point, it will set all speculators buy action.

Speculators trade

After initialization, the model will ask speculators who are not getting information or bankrupt to trade with each other.

When speculators enter the market, they set an order with a certain price at which they are willing to trade and search for a counterpart. If they can find the counterpart, they make the transaction and their agent variables such as cash and options will be updated.

Speculator may also trade with the market makers. When speculators are active (not getting information or bankrupt), they compare the price at which they are willing to deal with the market maker's ask and bid price according to their position. If the prices are suitable, they compare the market maker's price with

other traders' prices. if the market maker is offering the best price, they will make the transaction. Otherwise, they will trade with one of the other speculators who offers the best price.

Update speculators status

After trading, if speculator's cash is not enough to buy options, it will choose the getting information action. If speculators choose to get information, they will decide either to put in more money or take out money with certain probability. Due to disposition effect, the amount of money they put in will be twice as much as the money they taken out.

If a speculator's cash is less than zero, the speculator will declare bankruptcy. Accordingly, the colour of the speculator will become black.

Hedgers trade

Hedgers trade according to the simplified Black Scholes model and Delta Hedging strategy. The model uses option ratio and strike price to calculate call option price, put option price, Black Scholes call option price and Black Scholes put option price. The following are the formula the model uses to calculate the call and put option price. (Hall, 2020)

$$Call\ option\ price = Strike\ price * \left(-Option\ ratio + N(0,1)\right) - Futures\ price * (-Option\ ratio + N(0,1))$$

$$Put\ option\ price = Futures\ price * \left(Option\ ratio + N(0,1)\right) - Strike\ price * (Option\ ratio + N(0,1))$$

Then it will calculate final offset for both options price and futures price based on simplified delta hedging and hedgers' cash is updated. (Turner, 2018) The process is shown below:

If call option price > Black Scholes call option price:

$$Final\ offset = Deltac * Futures\ price - Call\ option\ price$$

else:

$$Final\ offset = Call\ option\ price - Deltac * Futures\ price$$

Update hedgers' cash.

If put option price < Black Scholes put option price:

$$Final\ offset = Deltap * Futures\ price - Put\ option\ price$$

else:

$$Final\ offset = Put\ option\ price - Deltap * Futures\ price$$

Update hedgers' cash

Set price limit

The upper and bottom price limits will be reset based on the final futures price after all the trading activities as the next time step's price limits.

5. Parameter Description

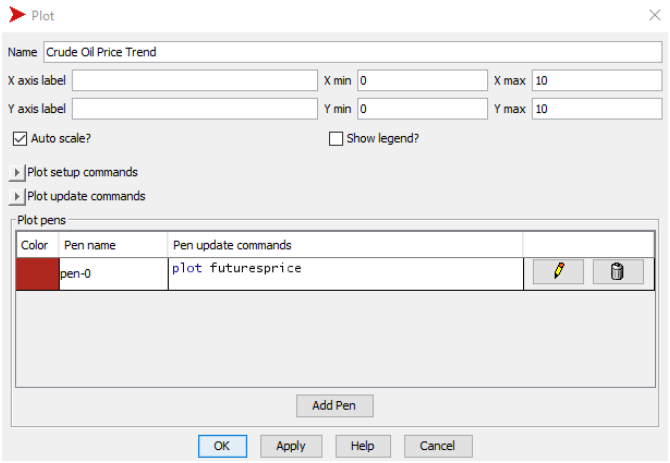
Parameter	Description and Justification
spot-price	Current market price for crude oil, at which crude oil is bought and sold immediately. The value of the spot price can be set by the analyst.

spread	The difference between the ask and bid price. The range of the spread is set to be within 1/5 of the spot price to limit the liquidity of the market. The value of the spread can be set by the analyst.
marketmaker-participation-rate	The probability of a speculator trads with the market maker. We want to control this rate to see how the trading activity of the market maker will affect the market.
speculator-participation-rate	The probability of whether a speculator chooses to trade or get information at the current timestep. This parameter is to simulate the situation when some speculators want to get information from other participates and pause their trading activity temporarily.
initial-speculation-bottom-line	The initial price bottom line at the beginning of the simulation. The value can be set by the analyst.
initial-speculation-upper-line	The initial price upper line at the beginning of the simulation. The value can be set by the analyst.
variable-price-limit	The difference between the variable price upper line and the variable price bottom line.
market-maker-cash	The initial total amount of cash the market maker is holding. The maximum amount is set to 10000 because our simulation market is a small market.
productivity	The intensity level of the production factor. The range of the intensity index is from 1 to 10. This parameter is used to quantify the effect of the production factor on the market.
policy-effect	The intensity level of the policy and regulation factor. The range of the intensity index is from 1 to 10. This parameter is used to quantify the effect of the policy and regulation factor on the market.
natural-effect	The intensity level of the natural factor. The range of the intensity index is from 1 to 10. This parameter is used to quantify the effect of the natural factor on the market.
prob-natural	The probability that the natural factor will affect the market. The probability of happening is ranged from 0 (never happen) to 1 (will happen).
prob-productivity	The probability that the production factor will affect the market. The probability of happening is ranged from 0 (never happen) to 1 (will happen).
prob-regulation	The probability that the policy factor will affect the market. The probability of happening is ranged from 0 (never happen) to 1 (will happen).
option-ratio	The ratio used to calculate the put option price and call option price.
speculation-mean-cash	The average amount of cash held by the speculators. It is ranged from 100 to 500 as the simulation market is small.
speculator-population	The number of speculators participating in the simulation. the maximum number is set to 100. The market size is small due to the hardware constraint. Otherwise, the simulation process will be very slow.
market-maker-options	The initial amount of the market maker's options to trade.

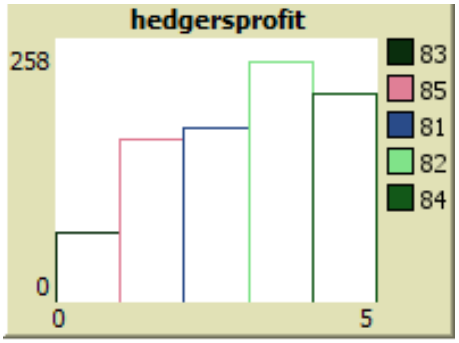
6. Result Analysis

6.1 Visualize the Price Change

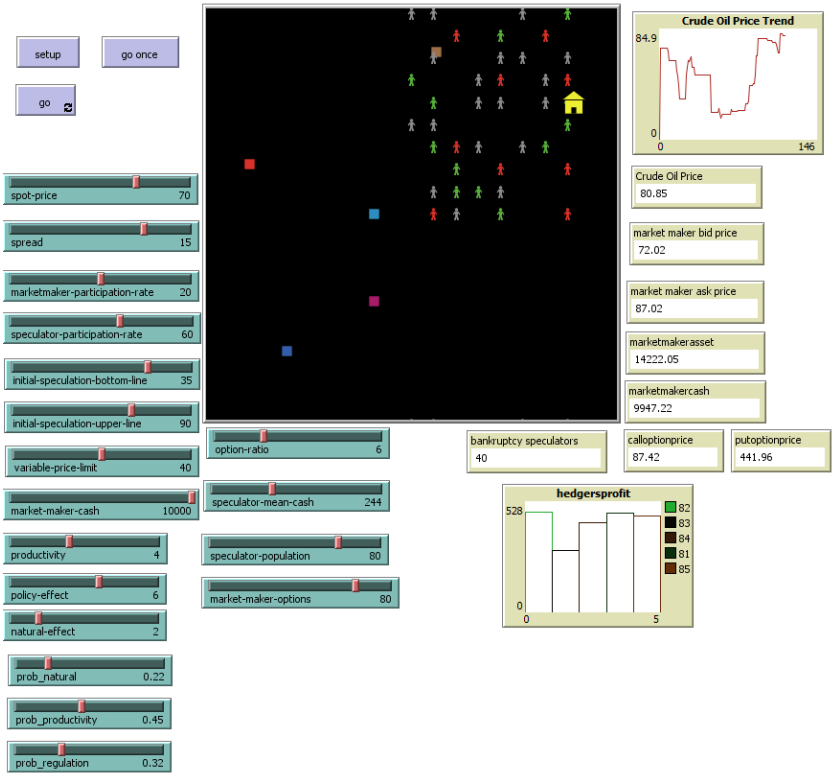
The model uses a plot to visualize the simulated crude oil price trend as shown below. Monitors are also setup to watch over the market maker bid price, market maker ask price, market maker asset, market maker cash, number of bankruptcy speculators, call option price as well as put option price.



The model also contains a plot to track hedgers' profit as shown below.



The graph below shows a screen shot of a sample run of our model in which the initial spot price is set to 70.



6.2 Analyse the Surviving of Speculators

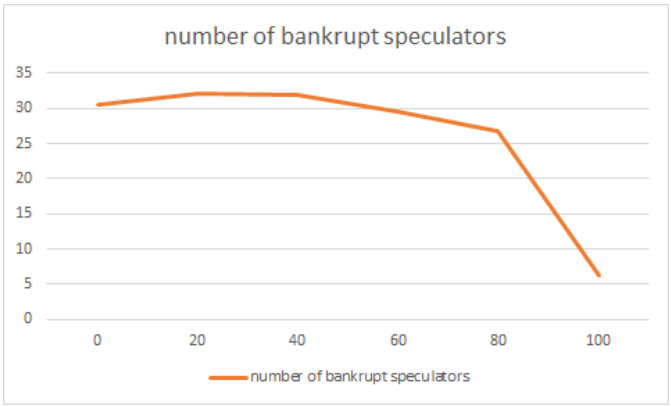
To find out how different factors affect the surviving of the speculators, the Behaviour Space is used to

carry out multiple runs of experiments. After several experiments, we find that there are mainly two parameters affecting the number of bankrupt speculators. One is the speculator participation rate, and another is the speculator initial mean cash. While keeping all other parameters constant, we tested the influence of these two parameters on the number of bankrupt speculators respectively.

Speculator participation rate experiment

While keeping other parameters constant, we compare the final number of bankrupt speculators after 100 timesteps when the speculator participation rate is 0, 20, 40, 60, 80 or 100. To get a more accurate view, we repeat the experiment for 20 times and calculate the average final number of bankrupt speculators after 100 ticks for each value of the speculator participation rate. The figures below show the change of the final number of bankrupt speculators with the change of the speculator participation rate.

Speculator participation rate	Average number of bankrupt speculators
0	30.6
20	32.15
40	31.85
60	29.6
80	26.85
100	6.3

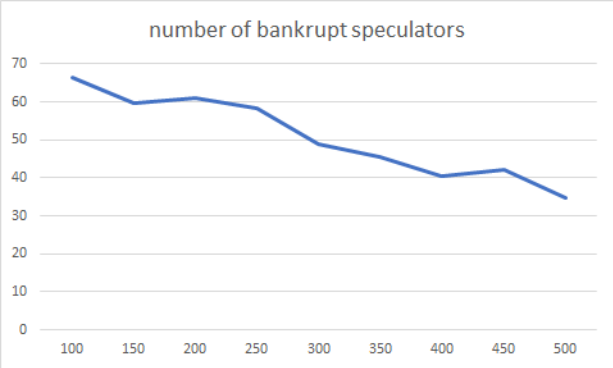


As we see, the number of bankrupt speculators decreases when the speculator participation rate increases. That means the more speculators choose to trade, the more speculators will survive.

Initial speculator average cash experiment

Similarly, while keeping other parameters constant, we compare the final number of bankrupt speculators after 100 timesteps when the initial speculator mean cash is 100, 150, 200, 250, 300, 350, 400, 450 or 500. To get a more accurate view, we repeat the experiment for 5 times instead of 20 times due to time and hardware constraint and calculate the average final number of bankrupt speculators after 100 ticks for each value of the initial speculator mean cash. The figures below show the change of the final number of bankrupt speculators with the change of the initial speculator mean cash.

Initial speculator mean cash	Final number of bankrupt speculators
100	66.0
150	59.8
200	61
250	58.2
300	49
350	45.4
400	40.4
450	42.2
500	34.8



As shown in the table and the graph, the number of bankrupt speculators decreases when the initial speculator average cash increases. That is easy to understand that the more money a speculator has at the beginning, the stronger ability the speculator has to survive in the end.

7. Model Validation

Our agent-based model offers the opportunity to model the behavioural problems in the commodity market and to study the consequences of different agents' behaviour in the market. As the price movement is the result of the interaction of the market players, the model targets the root drivers of the price change. Therefore, the modelling of individual market players' actions will be able to achieve a more realistic representation of the real-world commodity market system.

8. Conclusion

In conclusion, our group feel that there are still many difficulties we are facing when using agent-based modelling to model the commodity market trading due to its complexity and volatility. The largest challenge we face in this project is to quantify the market players' behaviour. The assumptions we make such as one single market and correlation between the spot price and the futures price may also differ from the real-world situation. However, we can still have a generic view and understanding of how some variables are affected by different factors in the commodity market through this project.

The further implementation of our project might be, instead of one single market, multiple market trading could be modelled and simulated, in which more market players such as arbitrageurs could also participate and bring new uncertainties to the markets.

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