**Research Project Assignment 2:**

**Model Description**

**John Hopkins University – Computational Modeling for Policy and Security Analysis**

My model will simulate a marketplace for the stock of a hypothetical corporation (corporation C). Every time period in the simulation can be thought of as one trading day. The agents in the model will be potential investors in corporation C, and there will be two types of investors: rational investors and irrational investors. These investors will differ in several ways, most importantly in how they determine whether to buy or sell shares of corporation C and their available cash to make trades. Every turn the agents will determine whether to buy or sell shares in corporation C, and will then either submit a buy/sell order, or submit no order. At the end of the round all orders are collected and settled, if possible. The price at which each order settles becomes the market price (Pm). This price is known to all agents, and is used by all agents when determining to buy or sell shares in corporation C. It is also the variable of interest in this model and will be recorded after every transaction. The simulation will end exogenously, when the user decides to stop running the simulation. I will go into more detail about the components of the model below.

**The Corporation**

Corporation C will have three global variables that will influence the simulation: number of shares, share price (Pm), and net income (I). Corporation C will have 200,000 shares available to trade, will have a starting share price of $100, and will have a starting net income of $1,000,000. The number of shares available to trade will not vary throughout the simulation – all shares will be held by agents and those agents will determine whether to sell their shares. The share price will vary as transactions are settled, as mentioned above. The net income will be updated every 65 turns, or once a quarter. The net income will be adjusted using the formula in figure 1 below; the new net income will be equal to the prior net income times one plus a random-normal number A, with mean .012 and standard deviation .02. All agents will have access to the net income, but only the rational investors will use it in their decision-making process.

Figure 1: Net Income Adjustment

**Rational Investors**

The rational investors make determinations about whether to buy or sell shares in corporation C by comparing their expected return of shares of corporation C to the expected return of similar assets. The expected return of similar assets, or target return (Rt) is uniformly set to .05 across all rational investors. This could be thought of as a result of the Capital Asset Pricing Model - it is the minimum return the rational investor would need from corporation C in order to justify investing in it versus an asset with a similar risk profile.

Rational investors determine their expected return of corporation C by first calculating their expected future net income of corporation C four quarters from now. Every rational investor calculates their own expected future net income of corporation C. They all do this calculation using figure 2 below; their expected future net income is equal to the last reported net income times four random-normal numbers. The random-normal numbers have the same distribution that will be used to adjust the actual net income every quarter because it is assumed that the rational investors have a solid understanding of corporation C, and thus are able to make predictions of future earnings that are in-line with the earnings actual distribution. The rational investors’ expectation of net income is updated only when the actual net income of corporation C is updated.

Figure 2: Net Income Expectations

After rational investors have updated their expectations for future earnings, they determine their future expected price. This is done by multiplying the expected earnings per share (expected future earnings / 200,000) times a fixed price to earnings (P/E) ratio of 20. This equation is used because the P/E ratio is often used to determine if a share price is fairly-valued. For example, if corporation C is a utilities company and has a P/E ratio of 25, but the utilities sector has an average P/E ratio of 20, then one could say corporation C is over-valued. Doing the calculation this way assumes that all rational investors have the same expectation of the P/E ratio for the corporation, and expect that the price will reflect a fair valuation. This assumption is used so that the expected price of the share is tied to the fundamental value of corporation C.

Once the expected future price of the shares has been calculated the rational investors determine their target price (Pt), which is the market price (Pm) at which they would meet their target return (Rt). For example, if a rational investor’s expected share price was $105, then in order to achieve a 5% target return they would have to purchase the stock at $100. Thus, at a price up to $100, the rational investor will put in a buy order, because at those prices they are expected to meet or exceed their annual target return. At prices above $100, the rational investor will sell shares of corporation C, if they possess any, because at that price they will not meet their target return, and thus would rather invest in other assets that will meet their target return. If the rational investor does not possess any shares, and the price is above $100, they will not place any orders. Rational investors will always attempt buy as much as they can, given their available cash when placing a buy order, and attempt to sell as much as they can, given their available shares when placing a sell order.

**Irrational Investors**

Irrational investors also determine a target price (Pt), however their target price is not tied to the fundamental value of the shares of corporation C. Irrational investors begin the simulation with a target price (Pt) that is a random number between 0 and 5000. Similar to rational investors, when the market price is below their target price, irrational investors will submit a buy order, and when the market price is above their target price they will submit a sell order. Similar to rational agents, irrational agents will attempt to buy and sell as many shares as they can in any given order. Irrational investors keep track of their profit and loss, which is just the difference between the current value of the shares they own plus cash on hand, and the original value of the shares they started the simulation with plus the amount of cash they started the simulation with.

Irrational investors adjust their target price by herding towards the most successful of the group. Irrational investors can see other irrational investors, and details about them, such as their price target and their profit/loss. Irrational investors will adjust their price target towards the irrational investor with the most profit/least loss. If multiple irrational investors are tied for most profit/least loss, the other irrational investors will adjust their target price towards the average target price of the most successful group. The irrational investors adjust their target price by moving half-way between their target price and the target price of the most successful group/investor.

Irrational investors also approach investing like one might a casino – they have a maximum loss (ML) they will accept before selling, as well as a maximum gain (Mg) they will take before selling. The maximum loss (ML) the irrational investor will accept is a random number between 0 and 1. Once their current assets (value of their stock plus cash on hand) divided by their starting assets (original value of starting stock plus cash on hand at model initialization) is lesser than or equal to that maximum loss (ML) value, the irrational investor will put in a sell order for all of their shares at market price. Similarly, the maximum gain (Mg) that an irrational investor will take before selling is a random number between 2 and 100, and once their current assets divided by their original assets is equal to or greater than their maximum gain (Mg), they will put in a sell order for all of their shares at market price.

Additionally, irrational investors exhibit irrational exuberance in the market. Every day that the value of their assets increases, they adjust their maximum gain (Mg) amount up 10%. However, the irrational investors also exhibit skittishness, as they will adjust their maximum gain (Mg) amount down on days when the value of their current assets decreases. On these days, irrational investors will lower their maximum gain (Mg) amount by 10%. These actions are intended to reflect how people act during a bubble – as the price goes up, people believe that it may continue to go up forever, but as it starts to come down people are quick to unwind that belief and exit the market.

Once an irrational investor sells their shares due to having reached their maximum gain (Mg) or maximum loss (ML), they will cease trading for 260 time periods. After 260 time periods, when the irrational investor returns to trading, or considering trading, they will reset their original asset value to their current asset value, and will also reset their price target (Pt), maximum loss (ML), and maximum gain (Mg) amounts.

**Market Clearing**

Every turn rational investors, and irrational investors will make decisions about whether to buy or sell. These decisions are made using the last market price (Pm) of the last turn, the previous day’s closing price. This is the price that rational and irrational investors will compare to their target price prior to submitting a buy or sell order, and it is the price irrational investors will use to value their current assets.

Once an agent decides to buy or sell, that decision is recorded along with the number of shares available to sell, the amount of cash available for shares, and the price of the order. The price of the order will be the target price of the agent for rational investors, and irrational investors who are not making the order decision based on their maximum gain or loss amounts being triggered. For sell orders, the price is the minimum price for which the investor will sell their shares. For buy orders, the price is maximum price for which the investor will buy shares. When an irrational investor has their maximum gain or loss amounts triggered, they submit a sell order with a price 0. This means that they will sell their shares at any price.

At the end of every turn, after all buy and sell orders have been recorded, all of the orders will be settled or cancelled. Orders are settled by matching a buy order with price Pb, to a sell order with price Ps that is below Pb. Once this match is made, a price for the order to settle at is made by calculated by selecting the number that is greater than or equal to Ps, less than or equal to Pb, and closest to the previous market price. For example, if a buy order of price $115 is matched with a sell order or $110, and the previous market price is $100, the orders will be settled at price $110, since it is the price in between $110 and $115 and closest to the $100. This price then become the new market price.

Once a buy order is matched to a sell order, and a settling price is determined, the number of shares being transferred is calculated. This is calculated as the minimum of the number of shares in the sell order, and the cash available to shares in the buy order divided by the settling price and rounded down to the nearest cent. If after this settlement the buy order still has cash remaining, it will be attempt to be matched with another sell order. Similarly, if the sell order still has shares remaining it may be matched with another buy order.

Orders are settled by matching buy orders to sell orders. The order in which buy orders are matched is random. This is because the agents will make their decision simultaneously (or in a random order if simultaneously is not possible), so matching the buy decision in any particular order would be random. Orders in real markets are typically settled in order based on the time they are received. Since all orders are placed and settled within one time period in this model, it does not make sense to follow this logic. Additionally, since the order in which orders are settled in real-markets is not based on other factors such as the order price, it does not make sense to settle orders by those factors in this model.

If an order cannot be matched, it is cancelled, and does not affect the market price. If only buy orders are received, all of the orders are cancelled and the market price rises to the minimum buy order price. If only sell orders are received, they are all cancelled and the market price rises to the maximum sell order price.

**Initialization**

When the model is initialized, a user-selected number of agents will be created. The agents will be split between rational investors and irrational investors by using a user-selected ratio. Each agent will be given a user-selected amount of cash that can be used to purchase shares. Additionally, the 200,000 shares of company C will be split uniformly across all of the agents. All of the other agent variables will be determined as described above.

**Visual Representation**

The agents in the model do not act within any sort of physical framework – where they are in the world does not impact what they can do or what information they have access to. Instead, the physical world will be used to visualize the behavior of the agents. The physical world will be comprised of a closed rectangular space with x coordinates between 0 and 5000, and y coordinates between -3 and 2. The x coordinates are used to show the market price (Pm) and the target price (Pt) of the agents. The y coordinates are used to show the decisions of the agents: -3 for irrational investors that have stopped trading due to their maximum gain (Mg) or loss (ML) being met, -2 or investors who would put in a sell order but do not have shares to sell, -1 for investors who put in a sell order and have shares to sell, 1 for investors who would put in a buy order but do not have sufficient funds, and 2 for investors who put in a buy order and have sufficient funds.

At initialization the agents will be randomly placed on the grid. Once the simulation begins, at the end of every turn the agents will move to the corresponding y coordinate, and to the x coordinate that most closely matches their target price (Pt). Irrational agents will be represented by circles, and rational agents will be represented by triangles. All of the patches in the world will be black, except for the patch with y coordinate 0 and x coordinate that most closely matches the current market price. That patch, the market price patch, will be bright green. This visualization of the world will not impact the simulation, but will give a graphical representation of how it is going in real time.

**Steps**

1. Set the market price to $100 and net income to $1,000,000.
2. Create a user-selected number of agents, with a user-selected ratio of rational to irrational investors. Agents are randomly place on the grid.
3. Agents are assigned a user-selected amount of cash, and are given a uniform amount of corporation C’s 200,000 shares.
   1. If there is not a round number of shares per agents, a random subset of agents receives an extra share.
   2. Irrational agents are assigned a price target, maximum loss amount, and maximum gain amount. Irrational agents are assigned a profit/loss of 0 and original value equal to the user-selected amount of cash plus the 100 times the amount of shares it receives.
4. If the time variable t is divisible by 65, a new net income is calculated and set.
5. All agents update their target price and submit buy/sell orders.
   1. Rational agents
      1. If the net income changed this period, re-calculate the expected future net income. Then use the expected future net income to determine the expected future price. Then use the expected future price and the target return to determine the target price.
      2. If the agent’s target price is higher than the market price, submit a buy order.
         1. If the target price is higher than the market price, but the agent does not have any cash available, the agent does nothing.
      3. If the agent’s target price is lower than the market price, and the agent owns at least 1 share of company C, submit a sell order.
         1. If the target price is lower than the market price, but the agent does not own at least 1 share of company C, the agent does nothing.
      4. The agent then moves to it the location on the grid the corresponds to its order decision and its target price.
   2. Irrational agents
      1. If the agent is inactive (because their maximum gain or loss amount was triggered), and they have been inactive for 260 time periods, the agent becomes active again and sets their original asset value to their current asset value.
      2. The agent calculates their current asset ratio by dividing their current assets by their original assets. The agent also calculates profit by subtracting their current assets minus their original assets.
      3. If the market price is down from the previous day’s market price, the agent reduces their maximum gain amount by 10%. If the market price is up from the previous day’s market price, the agent increases their maximum gain amount by 10%.
      4. If the current asset ratio is at or below the maximum loss or maximum gain amounts, the agent submits a sell order at market price. The agent then becomes inactive.
      5. The agent looks at the set of irrational investors that have a profit equal to the maximum profit. If the agent is included in that set it does nothing. If it is not included in that set, it finds the average target price of agents in that set. It then adjusts its target price by one-half the difference of its target price and the average target price of the group.
      6. If the agent’s target price is higher than the market price, submit a buy order.
         1. If the target price is higher than the market price, but the agent does not have any cash available, the agent does nothing.
      7. If the agent’s target price is lower than the market price, and the agent owns at least 1 share of company C, submit a sell order.
         1. If the target price is lower than the market price, but the agent does not own at least 1 share of company C, the agent does nothing.
      8. The agent then moves to it the location on the grid the corresponds to its order decision and its target price.
6. The market settles all of the orders.
   1. Buy orders are randomly selected and matched to sell orders that have a sell price Ps that is less than the buy price Pb. The matching orders are then executed at the share price that is between Ps and Pb, inclusive, and closest to the previous market price, Pm. A number of shares is then determined by taking the minimum of the shares available on the sell order and the cash available on the buy order divided by the settlement price. The cash and shares are then transferred between the agents. The price that the order settled at becomes the new market price, Pm, and the corresponding patch is turned bright green. This continues until all buy orders have been settled or cancelled.
   2. If no sell orders were received, the market price is set to the minimum buy price (Pb) of the buy orders that were received. The corresponding patch is turned bright green.
   3. If no buy orders were received, the market price is set to the maximum sell price (Ps) of the sell orders that were received. the corresponding patch is turned bright green.
7. Repeat steps 4-6 until the user stops the simulation.