**Research Project Rough Draft:**

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

**Research Question and Theoretical Arguments**

In the month of January, the market value of GameStop ballooned from a low of $1.4 billion to a high of $33.7 billion, before deflating into the low-single billions in mid-February (DeNapoli, Herbst-Bayliss, Franklin, 2021). The spectacle that was GameStop’s share price, along with the other “stonks” promoted on the WallStreetBets Reddit page (Regnier, 2021), seems to directly contradict the efficient market hypothesis, and the idea of *homo economicus* (the assumption that humans act with perfection rationality, often used in economic models). These ideas underpin much of what we think we know about how markets (particularly securities markets) work, and without them it isn’t clear what drives prices in these markets. If the price of a security isn’t just the expected value based on public information of the security, then what is it? If individuals don’t always make trades that are rational (i.e. maximize future utility), then how do they make trades? How does all of this affect prices in the market? The answer to these questions has implications for large sums of money, as evidenced by the GameStop saga.

The efficient market hypothesis states that a market is efficient if the prices in the market reflect all public information, such that earning a return higher than the expected return is not possible (Fama, 1970). This means that at any given moment the price in the market reflects the expected return of the asset. Since markets are comprised of people buying and selling an asset, this implies that people are buying and selling an asset based on their assessment of the expected return of the asset, and further, that their collective assessment accurately reflects the expected return. If the people in the market buy and sell the asset irrespective of their assessment of the expected return, for example by herding (Bikhchandani & Sharma, 2000), or if their assessment is faulty in some way, for example by displaying irrational exuberance (Shiller, 2000), it is not clear what the price will reflect. My research will attempt to model how the trading strategies of participants in a market affect the price of the market.

My research will focus on exploring the price in the market relative to fundamental price of the underlying asset. With regards to stocks, the underlying asset is a share of a company. The fundamental value of that share is the share of the net-income (or free cash flow) that the share represents, as this is what can be returned to investors. However, as described above, not all investors trade based on the fundamental value of the asset – some traders make decisions about trading the asset based on their neighbors, or based on recent price movements. My model will examine how these trading strategies, and the propensity of traders to use these strategies influences the market price relative to the fundamentals of the underlying company.

Computational modeling will be used in this research because it is able to account for the heterogeneous strategies and actions of the market participants and determine how those micro strategies and actions affects the market as a whole. This research focuses on the strategies and actions of the individuals in the market, so it is absolutely necessary that the modeling method used is able to capture this. Other modeling methods do not possess the ability to account for a large number of actors with heterogeneous strategies and are thus not suitable for this research.

**Model Description**

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. 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. If all orders cannot be settled, the market price is adjusted to a level that would have settled all of the orders. 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, or endogenously when the market price reaches $0. 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 1,000 shares available to trade, will have a starting share price of $1, and will have a starting net income of $50. 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 adjust at the end of every trading day in the direction that would settle the market; if more buy orders than sell orders were received, the price will adjust up to encourage more sell orders, the reverse is true if more sell orders are received. 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 that is set by the user (mean-ni-growth) and standard deviation that is also set by the user (sd-ni-growth). 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 a random-normal number. The random-normal number has a similar distribution to the one used to adjust the actual net income every quarter – its mean is 4 times the mean-ni-growth, and its standard deviation is 4 time the sd-ni-growth. This is 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 / 1,000) 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 $1.05, then in order to achieve a 5% target return they would have to purchase the stock at $1. Thus, at a price up to $1, 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 $1, 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 $1, they will not place any orders.

**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 10. 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.

Irrational investors adjust their target price in two ways: by adjusting their price based on the recent market price, and by herding towards target price of their neighbors. Every turn irrational investors will look at whether the market price went up or down at the end of the previous turn, and if it went up they will adjust their price target up 5%, and if it went down they adjust their price-target down 5%. After this, irrational investors will look at their 8 neighbors, and calculate the mean target-price of those neighbors. They then adjust their target-price by 10% of the difference between their current target-price and the mean of their neighbors’ target-prices.

**Placing Orders**

After all agents have updated their target-prices, they decide what order to place, and how many orders to place. All agents make these decisions in the same way. If the current market price is above their target price, they decide to make a sell order. If the current market price is below their target price, they decide to make a buy order. Each buy and sell order is for one share, and the amount of buy and sell orders that each agent places is determined by ratio of the current market price to the agent’s target-price. For sell orders, if agents have shares to sell, they will place at least 1 sell order, and up to the number of shares they have to sell. The amount of orders placed will scale up from 1 to the max as the current market price reaches 2 times the agent’s sell price, as shown in figure 3. For buy orders, agents will place at least 1 order, and will place up to the amount that they can afford given their available cash and the market price. The amount of orders place will scale up from 1 to the max as the current market price reaches 50% of the agent’s buy price, as shown in figure 4.

Figure 3: Sell Order Quantity

Figure 4: Buy Order Quantity

**Market Clearing**

Every turn rational investors, and irrational investors will make decisions about whether to buy or sell. These decisions are made using the market price (Pm) of the last turn. This is the price that rational and irrational investors will compare to their target price prior to submitting a buy or sell order. Once an agent decides to buy or sell, they then decide how many orders they would like to place, and then they place those orders. Every order is recorded, along with the target-price of the agent that made the order.

At the end of every turn, after all buy and sell orders have been recorded, the orders will attempt to be settled. If more buy orders than sell orders are recorded, then all the sell orders are automatically settled at the current market price, meaning each agent that placed one or multiple sell orders will lose that quantity of shares and gain that quantity of shares times the market price in cash. Then, a random number of buy orders equal to the amount of sell orders received are settled. For every buy order selected, the agent who placed the order gains one share and loses an amount of cash equal to the market price. After this, all of the buy orders are sorted by their target-price in descending order, and then the top number of rows equal to the difference between the number of buy and sell orders received is selected. The median target price of these orders becomes the new market price. This is because, all other things equal, that is the price that would settle the remaining orders – at that price half of the remaining orders would have decided to sell, while the other half would have still decided to buy.

If there are more sell orders than buy orders then everything is switched. All of the buy orders are automatically settled, a random number of sell orders are settled, the sell orders are sorted in ascending order by their target-price, a number of sell orders equal to the difference between buy orders and sell orders placed is selected, and the median target-price of that list is set as the new market price. If there were an equal amount of buy and sell orders, or if there were no orders placed at all, then the market price does not change.

**Initialization**

When the model is initialized, 100 agents will be created on a 10 x 10 grid, with each agent occupying one space on the grid. The agents will be split between rational investors and irrational investors by using a user-selected ratio, but the location will be random, i.e. there is no logic controlling where rational or irrational agents are placed. Each agent will be given $50 in cash that can be used to purchase shares. Additionally, the 1,000 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 exist on a 10 x 10 grid that wraps both horizontally and vertically. Agents are randomly placed on the grid, with each agent occupying one space, and do not move at any point. The physical space is primarily only important for irrational agents, whom adjust their target-price based on their 8 neighbors on the grid. Other than that procedure, the physical location of the agents does not actually impact the model.

Agents are assigned a color that correspond to their investor type – irrational agents are colored orange, while rational agents are colored green. Throughout the simulation the patches are given different colors based on the agent of that patch – a light blue if the agent wants to buy shares, a light brown if the agent owns shares and would like to sell them, and black if the agent would like to sell shares but does not own any. These colors do not impact the simulation, but are for reference as the simulation runs.

**Steps**

1. Set the market price to $1 and net income to $50.
2. 100 agents are created, with a user-selected ratio of rational to irrational investors. Agents are randomly place on the grid.
3. Agents are assigned a $50 in cash, and are given a uniform amount of corporation C’s 1,000 shares.
   1. Irrational agents are assigned a target-price that is a random integer between 0 and 10.
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.
   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. Irrational agents
      1. If the market price went up last period, then the target price is adjusted up 5%. If it went down, the target price is adjusted down 5%.
      2. Irrational agents adjust their target price by 10% of the difference between their current target price and the average of their neighbors’ target price.
6. All agents determine if they would like to buy/sell, and then submit their orders.
   1. If the agent’s target price is higher than the market price, they 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.
      2. If the agent has enough cash available, they will submit at least one buy order, but may submit as many as they could afford.
         1. The amount they decided to buy depends on the ratio of the current market price to their price target.
   2. 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.
      2. If the agent owns at least one share, they will submit at least one sell order, but may submit as many sell orders as they have shares.
         1. The amount they decide to sell depends on the ratio of the current market price to their price target.
7. The market settles all of the orders.
   1. If there are more buy orders than sell orders:
      1. All sell orders are automatically settled.
      2. A random number of buy orders equal to the number of sell orders are selected and settled.
      3. The buy orders are sorted in descending order by their target price, and a number equal to the difference between sell orders and buy orders is selected from the top.
      4. The median target-price of this list becomes the market price.
   2. If there are more sell orders than buy orders:
      1. All buy orders are automatically settled.
      2. A random number of sell orders equal to the number of sell orders are selected and settled.
      3. The sell orders are sorted in ascending order by their target price, and a number equal to the difference between sell orders and buy orders is selected from the top.
      4. The median target-price of this list becomes the market price.
   3. If there are an equal amount of buy and sell orders:
      1. All orders are settled and the market price stays the same.
   4. If there are no buy or sell orders:
      1. No orders are settled and market price stays the same.
8. Repeat steps 4-7 until the user stops the simulation or the market price reaches $0.

**Simulations**

My model examines the relationship between irrational (or non-fundamental) trading strategies and the market price of an asset. In order to test this relationship, I plan on conducting multiple simulations with varying levels of irrational agents. I plan on conducting simulations with a high level of irrational agents (75 of the 100), a medium number (50 of 100), and a low number (25 of 100). I also plan on varying the mean-ni-growth and sd-ni-growth. I want to vary these parameters so that they reflect different types of shares (e.g. a value stock versus a growth stock) to determine if the effects of irrational traders in the market are more forceful on certain types of assets. I plan on testing three different value-pairs for mean-ni-growth and sd-ni-growth: a low-growth low-variance, a medium-growth medium-variance, and a high-growth high-variance. For each of these pairs of parameters (e.g. High Irrational Agents and Low-Growth Low-Variance NI Growth), I plan on conducting 10 simulations, each that lasts 2700 turns (10 trading years), or until the market price reaches $0.

**References**

Jessica DiNapoli, Svea Herbst-Bayliss, Joshua Franklin. (2021). Exclusive: How GameStop missed out on capitalizing on the reddit rally. Retrieved 2/11/, 2021, from <https://www.reuters.com/article/us-retail-trading-gamestop-capitalraise-idUSKBN2AB14F>

Regnier, P. (2021). Stonks are bonkers, and other lessons from the reddit rebellion. Retrieved 2/11/, 2021, from https://www.bloomberg.com/news/features/2021-02-04/gamestop-gme-how-wallstreetbets-and-robinhood-created-bonkers-stock-market

Fama, E. (1970). Efficient Capital Markets: A Review of Theory and Empirical Work. The Journal of Finance, 25(2), 383-417. doi:10.2307/2325486

Bikhchandani, S., & Sharma, S. (2000). Herd behavior in financial markets. Washington, DC: Internet Monetary Fund.

Ref

Shiller, R. J. (2000). Irrational exuberance. Princeton [u.a.]: Princeton Univ. Press. ISBN: 1400824362