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Not All Drug Consumers Become Addicts: An Application of the Neuroeconomic Drift Diffusion Model

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Addiction is classified as a brain disease, but it is also a behavioral disease. Most people believe that drug abusers do not have the willpower or capability to stop consuming drugs once they have started. "Addiction is defined as a chronic, relapsing brain disease that is characterized by compulsive drug seeking and use, despite harmful consequences" due to the brain's structure changing as a result of chronic consumption of drugs (Rehm, 2009). Addiction needs to be addressed because it has negative consequences for the individual such as medical conditions including liver disease and lung cancer. The individual also faces consequences such as familial struggles, loss of employment, dependency on drugs for happiness and more. The total costs on substances abuse is approximately $700 billion in the United States, including crime related costs, productivity and health costs (Rehm, 2009). It is necessary that treatments for addiction ae a combination of medication and behavioral therapy in order to have successful results.

Economists define addiction according to two conditions: reinforcement and tolerance (Gruber & Koszegi, 2001). Reinforcement results when yesterday's consumption increases the marginal utility of today's consumption (Gruber & Koszegi, 2001). For instance, higher total utility is received from consuming more of a good and marginal utility is diminishing at high levels of consumption. Tolerance is characterized by a reduction in the utility from consuming the same amount of the good tomorrow as was consumed today (Gruber and Koszegi, 2001). The addict will need to consume greater amounts of the good in order to get the same high as the previous encounter with the good. It is important to note that there exists a third condition that may arise, but not everyone who is an addict experiences this condition. Withdrawal is when an addict abstains from consumption and experiences a negative physical reaction from this abstinence (Gruber & Koszegi, 2001). Withdrawal is measured by the level of dependency that an addict has for a good. As the addict reduces the level of consumption, the addict is also gaining less satisfaction from consuming that good. Economists defines addiction using this terminology in order to better understand how addiction works, but it is important to note that there exists similarities between the disciplines on how addiction is perceived, but not all professionals from the three disciplines agree on the other discipline's definition of addiction.

My research uses the theoretical framework of economics to model and predict the biological and behavioral outcomes from drug consumption whereas previous research has inadequately linked the biological and behavioral understandings of addiction. Most economic models that explore addiction and rational behavior focus on the outcome of a decision where as my research uses the Neuroeconomic Drift Diffusion Model in order to understand an individual's decision making process. This model is important to my research because it utilizes the perspectives from the three disciplines; Biology, Economics, and Psychology, in order to accurately depict the decision process.

II. Literature Review

The Rational Addiction Model, designed by Becker and Murphy, in order to comprehend how the Rational Addiction Model is used to understand rational behavior in mainstream Economics is known to be one of the standard models on addictive behavior. The model explores an individual consuming an addictive good with the intent of maximizing their utility despite knowing the potential consequences that comes with consuming an addictive good (Becker & Murphy, 1988). One of the weaknesses and limitations of the model is that the model holds preferences constant at all times. One of the difficulties looking at addiction is how the chemical structure of the brain is reacting to the addictive goods therefore preferences are being changed over time and the Rational Addiction Model does not fully account that. Although the Rational Addiction Model is the foundation for modeling drug consumption in economics, I expanded my research beyond the model in order to explore some of the suggestions made by other economists who have researched rational behavior. I came across the emerging field of Neuroeconomics, which combines biology, psychology, and economics to explain the human decision making process. This is a combination of how the brain functions along with the behavioral patterns that are monitored by economists and psychologists. Using my computational skills, I began to create a program that would simulate theoretical data of non-addicts and addicts on how they are making their decisions using the Neuroeconomic Drift Diffusion Model. It is important to note that this model has been used to look at the decision making process, but my research is focused on how the model can be applied to someone who is an addict.

The Rational Addiction Model

Most mainstream economists who are interested in the field of addiction and rational behavior use the Rational Addiction Model to strengthen their research, but like any model it has its strengths and weaknesses. The Rational Addiction Model (Becker & Murphy, 1988) formally models the utility received by an addict (i.e., a consumer) from consuming an addictive good. The model describes a consumer’s consumption behavior of addictive substances like cocaine, alcohol, coffee, gum, and other goods over time. Consumption is modeled over time, capturing current and future consumption of the addictive good. In terms of an addict, it is believed that their preferences are stable, but is it possible that through the biology of addiction that chronic consumption of the addictive substance results in changes to the brain to readjust the consumer’s preferences.

A limitation of this model is that there is no real way to measure the changing preferences of a consumer over time. The Rational Addiction Model also assumes that the discount rate is also stable. The discount rate, just as in any intertemporal model, discounts future benefits to the present value, assuming that gains received today are worth more than gains received tomorrow. Indeed, the discount rate is measured as the preference for immediate rewards divided by delayed rewards (Chabris, 2007). This means that relatively patient consumers have a lower discount rate than impatient consumers. Since the discount rate is stable over time in the Rational Addiction Model, the consumer will not be more or less patient towards the utility gained from consuming the addictive good in the future than their patience in the present or past. In the Rational Addiction Model, addictive behavior is no different from economic behavior and therefore, addictive behavior is economically rational (Tomer, 2001). The model fails to differentiate how negatively severe an addictive behavior is and the results that it can have on the individual. Although the Rational Addiction Model is used by most mainstream economists, I believe that the uprising field of Neuroeconomics better explains rational behavior, specifically addictive behavior.

The field of Neuroeconomics

Neuroeconomics is an interdisciplinary field that utilizes the foundations of psychology, neuroscience, and economics in order to better understand human decision making. Unlike most mainstream economic models that look at rational behavior, Neuroeconomics explores the decision making process as opposed to the outcome of a decision (Glimcher, 2009). Neuroeconomics, like mainstream economics, uses the concepts of rational agents and the concept of expected utility. Neuroscientists are determining which parts of the brain are active during the decision making progress and relating these parts of the brain to economics. For example, the limbic system is active when an individual is choosing immediate rewards as opposed to postponed rewards (Glimcher, 2009). Neuroeconomics is combing the mathematical computations that economics have developed to model decisions, utility functions, and discounting functions with the parts of the brain that activate when an individual is faced to make a decision. Neuroeconomists also look at how the individual interacts with the social surroundings that the individual is placed in (Glimcher, 2009). Neuroeconomics can be useful in understanding addiction because it focuses on the decision making process of the individual. Biologists look at how the chemical structure of the brain is changing when the individual consumes an addictive substance that could affect the individual's preferences. Neuroeconomics is useful in modeling addiction behavior because it takes into account the noise that affect the individual's preferences. This promising field can be contributed to the conversation on addiction and what is happening when addicts and non-addicts are making decisions.

III. The Neuroeconomic Drift Diffusion Model:

A general discussion of the Neuroeconomic DDM

The Drift Diffusion Model (DDM) is a psychological model that is used for when an individual is faced with two choices. The model shows that the time it takes to make a decision between two choices is informative about the individual's preferences (Krajbich, 2014). The DDM helps address stochastic choice, which means that there is inconsistency in the behavior of an individual (Krajbich, 2014). The Neuroeconomic Drift Diffusion model is an adaption of the DDM, in which the individual is no longer observing, but instead gaining randomized utility values from each good to help make a decision. This is a representation of how preferences are changing in addition as the brain's structure is changing when consuming drugs.

(1) $$V_t = V_{t-1} + d(U_x - U_y) + \mathcal{E}_t$$

Model (1) has the individual make a decision between good X and good Y. U_x and U_y represent the amount of utility gained from each good by the consumer. If the difference between the utilities is positive, the consumer decided to go with good X over good Y and the consumer chooses good Y over good X if the difference between the utilities is negative. The discount rate, the rate at which consumers prefer immediate rewards over delayed rewards, is represented by d(Charbris, 2007). The higher the discount rate the more impulsive a consumer is towards making a decision. The lower the discount rate, the more patient a consumer is when making a decision. The variable $\mathcal{E}_t$ represents stochastic choice, but also referred to as the noise. For the purpose of my work, $\mathcal{E}_t$ allows an individuals preferences to be constantly changing as oppose to their preferences being stable. The data on the graph will constantly be fluctuating, which is a demonstration of how the individual is deciding between the two goods and how their preferences are not constant throughout time. The variable V_t is the relative decision value is a stock value that the consumer uses as a way to store all the prior knowledge and experience the consumer has had with making a choice between good X and good Y. The most important part of the model is the threshold value, *a*, which in the original DDM it was a representation of the decision that the user makes, but in my model the threshold is a proxy for a state of mind.

The Neuroeconomic DDM used for addiction

I recreated the model Ian Krajbich developed in his paper and made changes to the model, so that it can be used in the context of addiction (Krajbich, 2014). In my adaptation of the model when the individual reaches the positive threshold (*a*) they have reached the addiction state of mind and they have reaches the abstinent state of mind once they reach the negative threshold (-*a*). In order to use my computational skills to create a set of theoretical data I needed to determine what variables I would keep consistent throughout my trials in order to see how the data changes. I decided that the two goods the individual would choose between in my programming would be drugs (good *X*) and all other goods (good *Y*). If you have a relative decision value of 0 it means that you have no prior knowledge over which choice you prefer over the other. Any relative decision value between the addicted threshold and the abstinent threshold meant that the consumer has been presented with drugs and has made a decision on whether to take them or pass. The addicted threshold received a value of 1 while the abstinent threshold received a value of -1. The utility gained from making the decision of having drugs over all other goods or vice versa is given a randomized value between 0 and 1. As the program keeps running t is represented by the times that the consumer is faced with making the decision.

I investigated one limitation and two extensions of the Neuroeconomic DDM.

(1) The limitation I explored was the relationship between the threshold and the interval of potential utility gained from consuming a good. This limitation consisted of changing the randomized utility range that the consumer could potentially gain from deciding to consume one of the goods. The intuition behind this limitation was to explore the relationship between the threshold and the range of the randomized utility values assigned. For example, if the random utility value that is assigned for good X is between 0 and 1, I changed it so that the range became between 0 and 2. This would also mean that I changed good Y's random utility value range to between0 and 2 as well.
(2) My second experiment involved changing the discount rates. I created three different simulations of discount rates in which I used a constant discount rate, an exponential discount rate, and a hyperbolic discount rate. The purpose of this experiment was to explore how type of discount affects the individual's impulsivity to make a decision.
(3) My third experiment, is an experiment that I designed with a decaying addicted threshold. The purpose of this experiment is an attempt to simulate what is happening when drugs are changing the brain's structure and functions. The part of the brain that is active when making a decision is deteriorating and changing as chronic consumption of drugs occurs therefore the individual would not be able to resist the drug. Therefore, the individual has reached the addictive threshold much more rapidly than if the threshold was to always stay at the value of 1.

IV. Results/ Limitations

Experiment 1: Threshold and utility dependency

In my first experiment I explored the relationship between the threshold and the interval of potential utility gained from consuming a good. I used thresholds of ± 20 to represent the addicted and abstinent thresholds, respectively, and d were set to 1 (no discounting). I changed the utility interval by dividing the interval for both goods by 2. The interval of the utility gained from each good would be from 0 to 10. The consumer had to consume drugs many more times before officially reaching a threshold. I also did another trial in which the interval was squared allowing the random utility to spread from 0 to 400. The time it took for the consumer to reach a threshold. The interval of utility is much greater than the threshold that within the first or second time of consuming the drug the consumer had already become addicted or decided that they were going to fully abstain from drugs. In my last trial, the utility for good X is a random number selected from the interval 1 to 5 and 20 to 30 for good Y. The threshold is set to 100 utils and d is set to 1 (no discounting). In this trial, good Y is chosen every single time you run the program because the utils gained from good Y is much greater than good X. In terms of addiction, the consumer is choosing to abstain instead of continuing to consume drugs. The utility gained from consuming an addictive good directly impacts the number of times a person consumes the good before being addicted, if they ever reach that threshold.

Experiment 2: The discount rate and addiction

In my second experiment, I investigated the impact of the discount rate on the time it takes to reach a threshold. I used a constant discount rate, an exponential discount rate, and a hyperbolic discount rate.

Throughout my trials I kept the threshold at $(\pm)1$ and the random utility gained interval 0 to 1. The only thing that was changing throughout my trials was the discount rate. I first simulated model (1) using different discount rates: 1, 0.8, 0.5, 0.2. (See figure 1.) Unsurprisingly, consumers were more likely to reach a threshold following fewer chopises as the discount rate increased, meaning that the consumer is more impulsive.

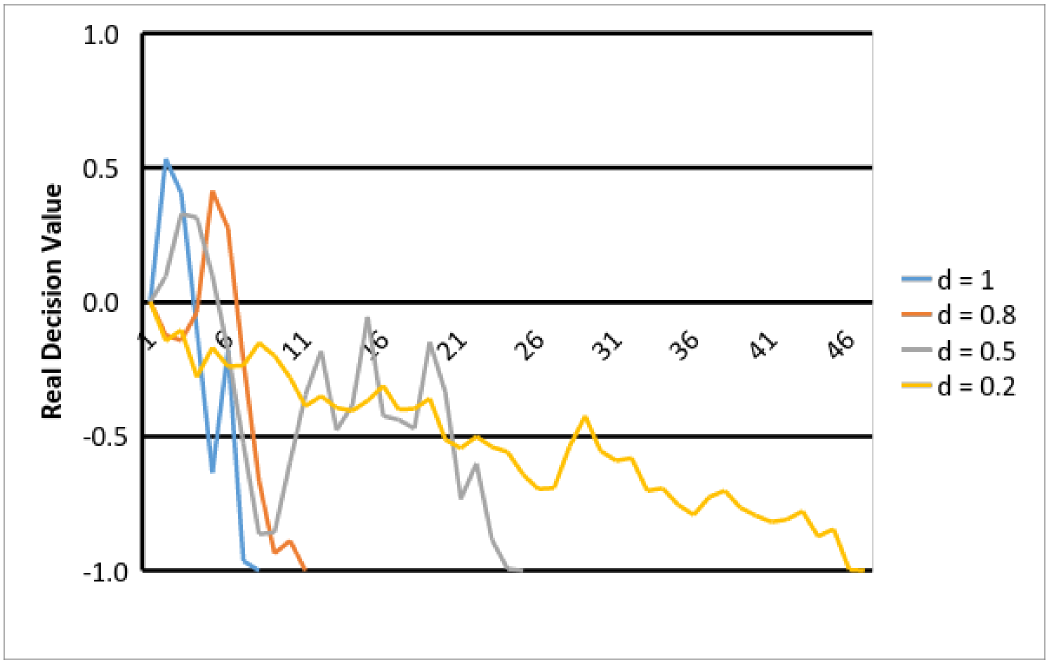

Figure 1. The Neuroeconomic DDM with Constant Discount Rates

Next, I applied an exponential discount rate:

(2) $$V_t = V_{t-1} + d^t(U_x - U_y) + \mathcal{E}_t$$

It is important to note that the equation now has a d^t to represent that the discount is growing exponentially. This means that the discount is changing every time someone is presented with the two goods in order to make a decision. Exponential discounting implies that the marginal rate of substitution between consumption at any pair of points in time depends only on how far apart those two time periods are (Charbris, 2007). The results of this experiment is that the stochastic behavior of the individual eventually reaches a constant state know as stable preferences (see figure 2). The relative decision value in this experiment was not changing over time because of the marginal rate of substitution, the additional value being added to the stock value was so small it did not make a difference. I used a discount rate of 1, 0.8, 0.5, and 0.2. In each trial, the relative decision value was asymptotic and less than the absolute value of the threshold. The consumer never reached a threshold in any of the trials.

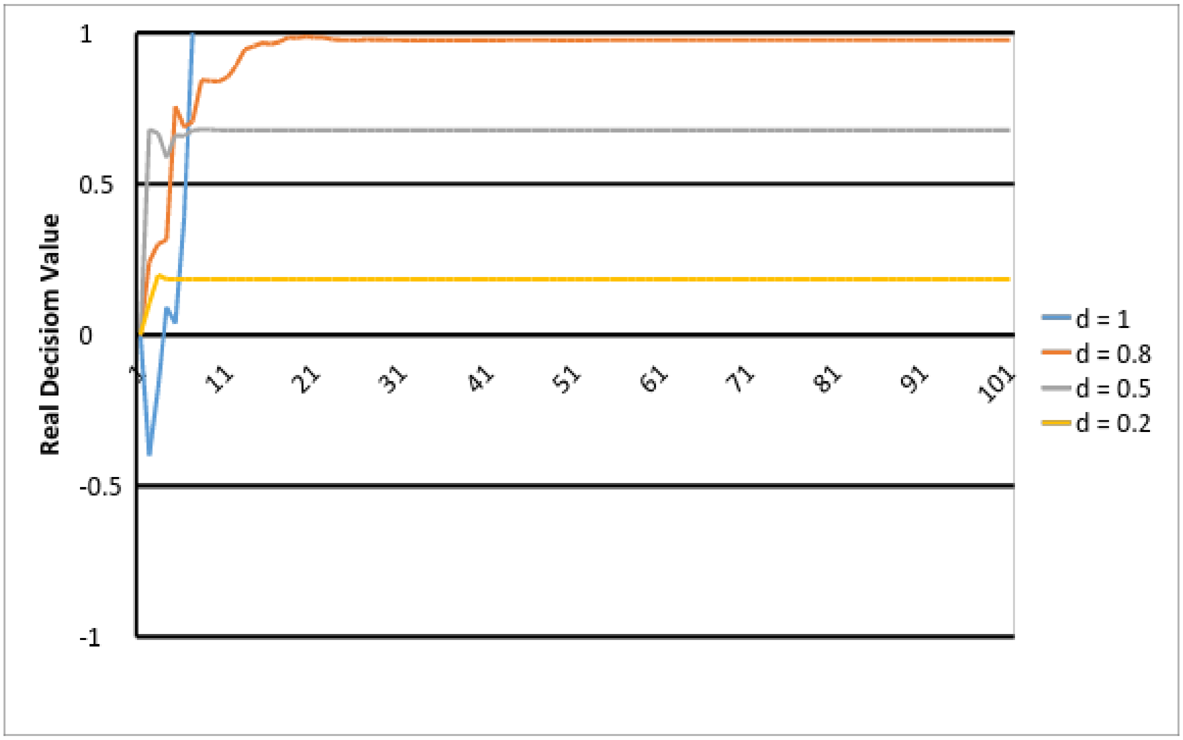

Figure 2. The Neuroeconomic DDM with Exponential Discount Rates

Finally, I explored the time to reach a threshold if the model included a hyperbolic discount rate:

(3) $$V_t = \beta(V_{t-1} + d(U_x - U_y) + \mathcal{E}_t)$$

Hyperbolic discounting is dynamically inconsistent; the consumer's preferences change over time. The values are changing rapidly in small delay periods, but then in the long delay periods the values are changing slowly (Charbris, 2007). Consumers are making choices that their future self would not have wanted to make. The value of the future rewards are lower than in exponential discounting. Using a hyperbolic discount rate, the model predicts that not all consumers will become addicted or abstinent (see figure 3).

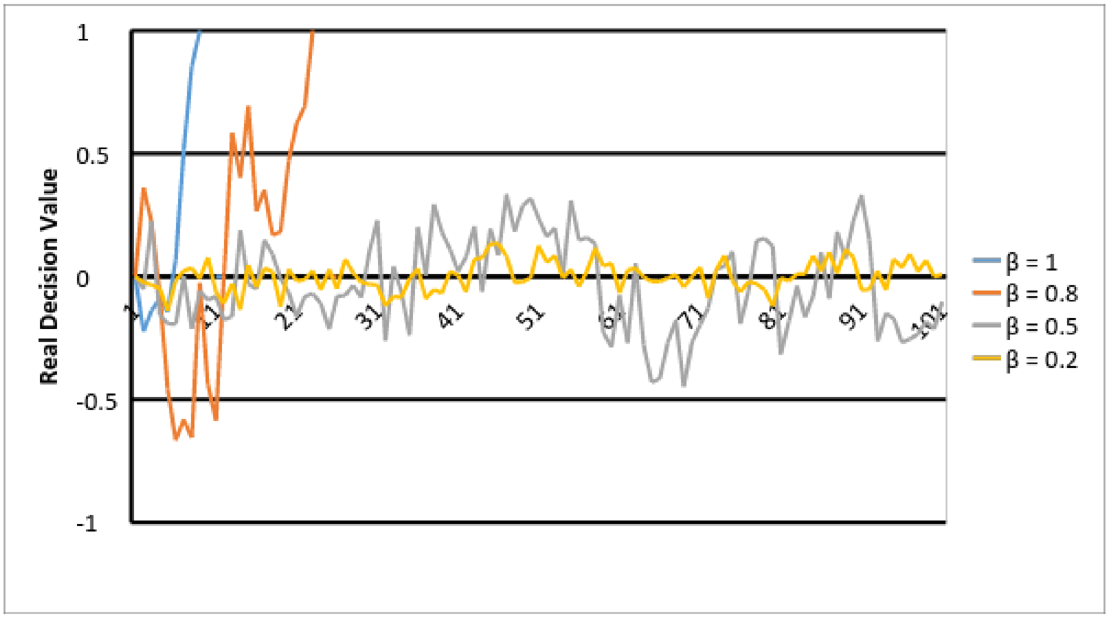

Figure 3. The Neuroeconomic DDM with Hyperbolic Discount Rates

I set β to 1 and 0.8 to start off my trials. In this trial the consumer eventually reached a threshold, but when β was set to 0.5 and 0.2, the consumer did not reach a threshold after consuming the drug more than 100 times. When using the hyperbolic discounting rate, there were consumers that became addicted, consumers that abstained, and consumers that consumed drugs but never reached a threshold. The hyperbolic discount rate was the discount rate that resulted in all three options unlike the constant discount rate that always reached a threshold, and the exponential discount rate that never reached a threshold. The hyperbolic discount rate displays stochastic choice perfectly because we see that volatility in the relative decision value.

Experiment 3: The decaying addicted threshold

In my last experiment, I decided to decay the addicted (positive) threshold in an attempt to demonstrate what is happening as an individual is consuming drugs. In biology, drugs are changing the structure of the brain and the functions of the brain during chronic consumption of the drug. I wanted to represent this effect by showing that the addicted state of mind is easily reached when the individual is not capable of resisting the temptation of consuming drugs. The threshold (a) is being divided by t, the times that a consumer is faced with the decision in model (1). This allows the addicted threshold to decay as the relative decision value is increasing. The amount of time that it takes a person to reach the addicted state of mind becomes faster when the drug is more desirable due to the changes in the brain that are occurring from consuming the drug (See figure 4). The amount of time that the individual is faced with the decision is cut by about half from the original amount of time it takes. For instance, a person who made 20 choices before reaching a threshold, would now reach a threshold following 10 choices. The abstinent threshold remains unchanged in this experiment because the chemical structure of the brain are being altered by the consumption of the drug in a way that the drug is more appealing to the consumer. This would allow the addictive state of mind threshold to decay, while the abstaining state of mind remains constant due to the fact that the drug is more alluring than abstaining.

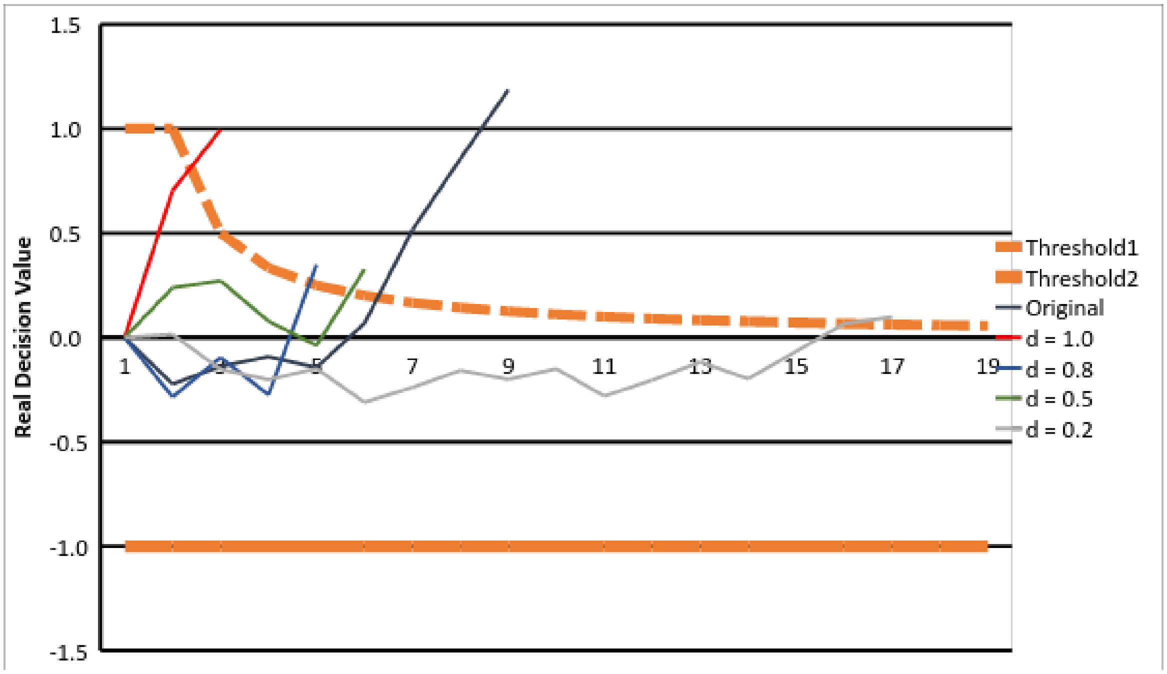

Figure 4. The Affect of Drugs on the Brain Using the Neuroeconomic DDM

V. Conclusion

The United States estimates about $700 billion used in health and productivity, and crime related scenarios having to do with drug addiction. Nearly 95% of untreated addicts die due to their addiction and only 3% of patients that need treatment for alcohol abuse actually get it. Addiction is a serious issue in the United States and in the world, so it is an issue that needs to be addressed with the proper treatments. A clear policy goal is therefore to reduce consumption of addictive substances. My results suggest that efficient policies to prevent addiction should target all the drug consumers with the exception of those who choose abstinence to start off and those who later become abstinent. These two groups represent the two groups of people that consume the majority of drugs. The third group, those who consume and later become abstinent, should not be targeted. This would be an inefficient use of resources given that the consumers became abstinent without any policy intervention.

Future research should show how to incorporate social's influence and personal influence on an individual's decision process. This would be useful in being able to accurately depiction of noise for each individual in a way that the program could learn and potentially predict how the consumer's preferences are changing after being presented the decision to consumer drugs or not. Another extension of this research might be to incorporate the impact of successful drug treatments on an individual's decision process. Theoretically, drug treatment would individuals to being abstinent as opposed to being addicted. The interesting part of that is to determine whether the individual’s choice is changing or if it is the abstinent state of mind threshold that is incrementing in a similar fashion to how the addictive threshold decayed. The consumer would be more alluring to the abstaining threshold as opposed to the addictive threshold.

VI. References

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