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Advancing Rationality with Sustainability: An Analysis of Agent-Based Simulation

Osman Goktug Tanrikulu
Portland State University

Advancing Rationality with Sustainability

An Analysis of Agent-Based Simulation

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Today, falling trends of species and ecosystem in the world due to overconsumption and destruction of natural resources are at critical levels. It is vital for humanity to operate with sustainable and resilient modes of production and consumption. In this regard, this paper examines the basic premise of rationality and introduces sustainability as an advancement to the theoretical concept of rationality. Thus, a rational mindset and a sustainable mindset are compared under depletion of environmental resources. The understanding of rationality in the analysis is based on Garett Hardin's (1968) 'the tragedy of the commons' model, in which actors are self-interested and individualistic while seeking resources. Conversely, a sustainable mindset acknowledges environmental limitations and takes action accordingly. By utilizing agent-based modeling, both rational and sustainable mindsets are modeled, and their relative behavior are put into action in computer simulation. The results reveal that the basic understanding of rationality is not always going to maximize the utility of agents. Instead, there may be environmental conditions where having a sustainable mindset generates more wealth. In a scenario of resource depletion, the chances of survival decrease for rational agents. Their situation is exacerbated if their level of greed increases. However, the sustainable agents continue making stable wealth even with limited environmental resources. Rational actors must develop a sustainable mindset in order to acclimatize themselves to environmental deterioration.

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Introduction

One of the most alarming global challenges faced today is environmental damage and destruction all across the world due to human overconsumption and exploitation of natural resources. Ecosystems and biodiversity including animal species are increasingly affected by pressures from unsustainable agriculture, fisheries, mining and other human activities that contribute to habitat loss, degradation, overexploitation, climate change and pollution. For example, between 1970 and 2013, the population of the world's wild animals decreased 58 percent.[1] According to the Ecological Footprint assessments, a measure of the relationship between human behavior and the Earth's resource capacity, the regenerative capacity of the Earth is not sufficient to accommodate the current human demand. Currently, the capacity of at least 1.6 planet Earths is needed to meet the goods and services of human consumption each year.[2] In this day and age, "the global population is cutting down trees faster than they regrow, catching fish faster than the oceans can restock, pumping water from rivers and aquifers faster than rainfall can replenish them and emitting more climate-warming carbon dioxide than oceans and forests can absorb."[3] The overconsumption of Earth's renewable resources threatens the environmental systems and the future of humanity.

Current economic systems, governance practices, as well as the social values of consumerist societies are driving humanity to an unsustainable future. "Structural elements of these systems such as the use of gross domestic product (GDP) as a measure of well-being, the pursuit of infinite economic growth on a finite planet, the prevalence of short-term gain over long-term continuity in many business and political models, and the externalization of ecological and social costs in the current economic system encourage unsustainable choices by individuals, businesses and governments."[4] However, protecting the planet's natural capital and its ecosystem is in people's primary interest. With a weak or destroyed natural environment, it will not be possible for humanity to create a fair and a prosperous future, conquer poverty and improve health. Significant changes must take place within the global economic system in order to inculcate a vision that the Earth has limited resources. Research advocates "changing the way we measure success, managing natural resources sustainably, and taking future generations and the value of nature into account in decision-making."[5] It is critical for humanity to operate within sustainable limits of production and consumption. To prevent further degradation of the environment a mindset must be developed that comprehends resource boundaries and promotes a sustainable way of life for the future.

This paper explores the consequences of environmental factors in decision-making modeling. The purpose is to demonstrate how different ways of thinking become important under scarce resources. By utilizing agent-based modeling and an artificial behavioral space, the performances of rational and sustainable mindsets are compared under various environmental conditions. Variations in behavior are tested in a simulation environment in which different factors can be manipulated and experimented. The agent-based models that are designed in this study use the simulation software NetLogo 6.0.[6] Overall, the findings suggest that agents who acknowledge the limitations of environmental resources and act accordingly benefit over agents who are self-interested and individualistic.

Theoretical Framework

Rationality is the leading concept of most decision-making models. Classic economic theory, modern decision theory and game theory all utilize the concept of rationality. According to Sidney Verba, a rational actor makes a "cool and clearheaded ends-means calculation" after considering all possible courses of action and attentively weighing the advantages and disadvantages of each of them.[7] Modern formal decision theory and game theory suggest that optimal choices arise out of compelling and systematically defined situations. In these situations, rationality alludes to consistent utility-maximizing computation or adjustment to specific impediments. From the perspective of economics, a rational actor would select the most efficient alternative, which maximizes output compared to input, or minimizes input considering output. For instance, among different goods, a rational consumer chooses the one that will create maximum usefulness or advantages with the lowest cost. In modern decision theory, rational decision-making is about choosing among certain alternatives with each one having a particular set of consequences. The agent ranks each of the consequences in terms of its benefits and chooses the preferred alternative. If the consequences are unclear, the decision maker chooses an alternative that has the greatest utility expected. Game theory applies the same logic of utility maximization but additionally emphasizes how one actor's best choice can be dependent on another's.[8]

While many theories in different academic disciplines use the concept of rationality, there is hardly any consensus on the specifications of the concept. There are various perceptions and conceptualizations of rationality emphasizing distinct dimensions and thus various methodological tools to attain it. For instance, procedural rationality identifies the concept with "omniscience."[9] It is assumed that an actor knows the consequences of all his actions precisely, and he has clearly defined preferences. Procedural rationality also assumes that an actor correctly judges the preferences of other relevant actors and their possible response to his strategic choices. According to this view, rationality excludes misconceptions or flaws of human cognition, and omits emotional or psychological shortcomings.[10] On the other hand, those who define rationality instrumentally, provide a more limited view of the concept. According to instrumental rationality, a rational actor will choose the option that produces the more preferred result when faced with two alternatives. Instrumental rationality relies on two assumptions: connectivity and transitivity. Connectivity implies that an actor has the ability to compare achievable outcomes and logically evaluate them. Transitivity means that if a player chooses option a to b, and b to c, then he will choose a to c. Assumptions of instrumental rationality are useful for constructing theories of rational or psychological choice.[11]

Contrary to the classic economic perspective of rationality, Herbert Simon proposes bounded rationality highlighting the limitations of individuals' decision-making. Simon outlines the assumptions of traditional economic theory concerning a rational economic agent as the use of complete information, having a well-organized and a stable preference system and the ability to calculate utility for every alternative. However, according to Simon, individuals do not seek to maximize their interests through a specific pathway. He points out that individuals do not have access to all the information needed. Besides, even if they had full access, their cognitive capacity and time availability are not going to let them digest and process all that information. Therefore, Simon suggests approximate rational behavior to account for actual access to information and actual computational capacities. Rather than finding the optimal choices, decision-makers seek satisfactory solutions.[12]

These different theoretical perspectives express the dynamic concept of rationality and the robust nature of the academic dialogue surrounding this concept. The concept of rationality can become even more complex when environmental factors are added into the picture. Garett Hardin is one of the first scholars demonstrating how rational actors can end up in suboptimal outcomes in to environmental settings. Hardin came up with the expression "the tragedy of the commons" modeling the anticipation of environmental degradation whenever a scarce resource is in use by many individuals collectively. Hardin explains his model with the example of a pasture open to everyone. The logical structure is portrayed from the perspective of rational herdsmen. According to Hardin's illustration, each herder benefits from using the pasture. Being rational, it is expected that each herdsman will try to have as many cattle as possible on the pasture to maximize their gain. Herdsmen question the utility that is going to be gained as a result of adding one more animal to their herd. The positive side is all the earnings from the additional animal; thus the +1 utility. In contrast, the negative side is overgrazing due to adding one more animal. Rather than bearing the full negative utility individually, the effects of overgrazing are shared by all the herdsmen. Hence, the negative utility for each herdsman is a portion of -1. Because negative utility is distributed equitably among the herdsmen rather than being experienced individually, each and every rational herdsman sharing this commons would have this same decision-making calculus – adding more and more animals to their herds. As a result, the "tragedy" occurs.[13] "Each man is locked into a system that compels him to increase his herd without limit – in a world that is limited."[14] When each man pursues his own interest on a commons without regard for others, destruction ensues and eventually brings downfall to all.[15] Hardin's model is important in terms of portraying the dichotomy between overconsumption and scarce resources.

Scholar Richard Campbell also drew attention to rationality's theoretical paradox. The prisoner's dilemma game reveals how rational individual strategies can lead to collectively irrational results. According to the game, two men, A and B, are held separately by the police charged with a joint crime. The prosecutor offers a deal to the prisoners who are in separate cells and unable to communicate with each other. Each prisoner is told that even if they don't confess, there is enough evidence to incarcerate them for a year. If one confesses and the other does not, the former will go free but and his silent accomplice will be sentenced for ten years. If both confess their crime, each one will be sentenced for nine years. The circumstances for the prisoners are summarized in Table 1.

Table 1. The Prisoner's Dilemma

		Prisoner B	
		Not Confess	Confess
Prisoner A	Not Confess	1 Year	10 Years
	Confess	None	9 Years

From the perspective of prisoner A, prisoner B has two possible alternatives; he is either going to confess or not. Either way, if A is rational, he would confess in order to get fewer years. If prisoner B confesses, then confessing will be better for A. If B does not confess, it is again better for A to confess – serving no jail time. The same reasoning applies to prisoner B as well. Consequently, if both A and B are rational, they will both confess and end up serving nine years in jail. Therefore, the prisoner's dilemma game portrays how rational human beings can achieve irrational outcomes.[16]

Similarly, Mancur Olson depicts, in *The Logic of Collective Action*, how individuals fail to pursue their joint welfare. Olson challenges the general idea that when acting on behalf of their common interests, groups of individuals are expected to act for the common interests like single individuals would have acted for their personal interests. Previous research argued that a group of rational and self-interested actors would act collectively if they have a common interest or objective, which is going to make all of them better off. However, Olson claims that the proposition that groups will act on their self-interest due to their rational and self-interested behavior is actually not correct.[17] In fact, "unless the number of individuals in a group is quite small, or unless there is coercion or some other special device to make individuals act in their common interest, rational, self-interested individuals will not act to achieve their common or group interests."[18] Consequently, when members of a large group try to maximize their personal welfare rationally, they will not act to promote their common or group objectives unless there are other factors such as coercion.

Olson points out the role of organizations as a means to attain common or group interests. Organizations can execute a function when there are common or group interests – sharing a single purpose or objective. Even though organizations frequently attend to personal interests, their essential quality and core function is to further the common interests of groups of individuals. Individual, unorganized action won't be able to further that common interest, or it won't be able to further it sufficiently.[19]

Elinor Ostrom brought a new perspective to the tragedy of the commons, the prisoner's dilemma and the logic of collective action, which all depict how rational individuals can create irrational outcomes. All of these models portray how people jointly use a resource in a natural setting and how individuals jointly produce a suboptimal result. Ostrom advanced scholarship on rationality by applying methodological individualism to comprehend cooperative behavior and institutions.[20] She brought a new collective action dimension to Hardin's argument in "The Tragedy of the Commons" notwithstanding rational choice individualism.[21] Ostrom argues that through institutions in which there is shared behavior and egotistical individualism is regulated, commons can be governed. In order to prevent the destruction of natural resources, some scholars have historically recommended state control and some suggested the privatization of those resources. However, Ostrom asserts that "neither the state nor the market is uniformly successful in enabling individuals to sustain long-term, productive use of natural systems."[22] Instead, communities of individuals constructed institutions, dissimilar to the state or to the market, to manage resource systems with certain level of success over time.[23]

Rational and egotistical individual actions in pursuit of maximizing self-interest can be regulated under institutions as the shared decisions and behaviors.[24] This perspective sees institutions as rules, norms and designed constraints, which organize social, political, and economic interactions.[25] According to Ostrom, rules are important in terms of decreasing the uncertainty that is caused by the unpredictable behavior of individuals and resource systems:

> *In all cases in which individuals have organized themselves to solve CPR [common-pool resource, such as inshore fisheries, communal forests, smaller grazing areas, groundwater basins, and irrigation systems] problems, rules have been established by the appropriators that have severely constrained the authorized*

actions available to them. Such rules specify, for example, how many resource units an individual can appropriate, when, where and how they can be appropriated, and the amounts of labor, materials, or money that must be contributed to various provisioning activities. If everyone, or almost everyone, follows these rules, resource units will be allocated more predictably and efficiently, conflict levels will be reduced, and the resource system itself will be sustained over time.[26]

Ostrom's core argument is that individuals are more likely to generate and preserve the commons when they have feasible and dependable information, which is crucial in terms of working out the costs and benefits of resource decisions, and when they have opportunities to set the rules of the scheme.[27] Thus, Ostrom theorizes on self-organizing and self-governing forms of collective action. Unlike Hardin[28], Ostrom argues the tragedy of the commons is not the inevitable result for every resource. The outcome of resources depends "on the existence of institutions governing access, utilization, management, exclusion, ownership and transfer of ownership."[29] Consequently, despite the popularity of individualistic economic thinking, Ostrom proposed a vision of cooperative behavior which does not depend on a centralized state.

Modeling

Agent-based models are composed of agents that interact within an environment. Agents can be independent computer programs or separate parts of a program representing social actors, such as individuals, organizations, firms, or nation-states. Agents are programmed to respond to the computational environment, which is to simulate the behavior of social actors in real environment. Agent-based simulation offers the possibility to represent people's decision rules.[30] In agent-based modeling terminology, decision rules are the algorithms of the agents that let their interaction with each other and with the environment. The way people think or their logic is reflected in agent-based modeling as decision rules. As a mean to simulate the behavior of social actors in a real environment, the decision rules should be explicitly defined in the models.

In this study, the agents' decision rules rely on two assumptions. The first assumption applies rationality on resource utilization based on the calculations of actors in Garett Hardin's the tragedy of the commons model.[31] According to this model, rational actors would not hesitate to consume the resources of the commons for their individual interests. Therefore, when rationality is the primary driver of an actor, it is expected that this person would utilize the resources in its environment to increase its wealth as much as possible. It is difficult to portray an abstract concept like rationality in a concrete way, especially in an artificial environment. Therefore, 'generating wealth via resource usage' is employed as a basic indication of one's rational mindset:

> *The higher the level of rationality of an actor, the more it will obtain the resources in the environment to maximize its utility. The lower the rationality of an actor, the less it will extract the resources around to maximize its wealth.*

The second assumption points out a particular mindset that can be presented as an additional dimension to the basic notion of rationality. The purpose is to identify a mindset that is going to advance rationality's self-interest seeking individualistic premise.

Thus, this analysis takes 'sustainable mindset' as a factor that can be tested against the first assumption. People with a sustainable mindset are aware of environmental trends including diminished biodiversity and degradation of ecosystems in the world. Hence, they choose a way of life that avoids the overuse of resources. In other words, people with sustainable mindsets limit their resource consumptions according to Earth's environmental capacity.

> *The more the sustainable an actor is, the more it will restrain from conserving resources to maximize its utility in the long-term. The less the sustainable an actor is, the more it will disregard conserving the natural resources for the sake of maximizing its immediate interests.*

The analysis in this study focuses only on the aspects of the rational and sustainable mindsets addressed in the assumptions. Rationality and sustainability are abstract concepts with many different layers and facets. However, to run an experiment on these mindsets and observe the consequences, certain aspects of these systems have to be isolated. Agent-based modeling and virtual simulations help us peel off the layers of these mindsets and overcome difficulties of isolating abstract human systems. Thus, agent-based modeling is utilized as a computational method to test the behavioral consequences of the rational and the sustainable mindsets.

The basic connection of the rational and the sustainable mindset with resource extraction is simulated in NetLogo through various models. The analysis avails several models as a means to capture the behavioral pattern of rationality in realistic terms. Starting from the most basic and ending with the most advanced, the models will be presented one by one to explain how different dimensions of rationality are addressed. The models used in this study utilized the codes of Sugarscape and Wealth Distribution models, which can be reached from the Models Library of NetLogo.[32]

Model Development & Testing

Model development and testing of this study is conducted hand in hand. The core behavioral principles are tested on various models. Testing procedure is applied not only in terms of portraying the intended behavior in the best way, but also in terms of introducing new variables to make the model as similar as possible to real-life scenarios.

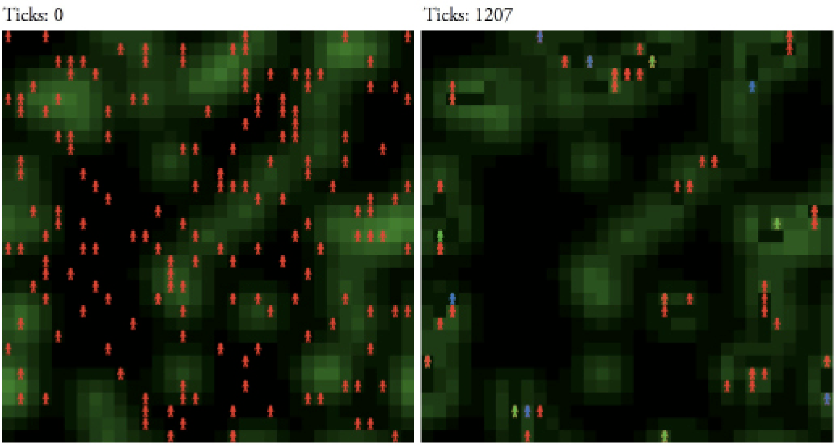
The analysis starts with the Basic Rationality Model, which is depicted in Figure 1. The NetLogo codes of all the models in this study can be found in Appendix I to replicate and trace. The left-hand side picture is a screenshot of the simulation before it was launched. The simulation begins with random distribution of resources and agents. The left picture in Figure 1 shows the randomly created red agents and the green resource mountains in the artificial simulation environment. The most basic variable that is used in the model is 'rationality'. Every agent is created with a random score of rationality from 1 to 10. The behavioral rule of the agents is to go to the resource mountains and to extract resources according to their levels of rationality:

> *The higher the level of rationality of an agent (turtle), the more it will extract from the green resource mountains (patches).*

For instance, when all the other variables are held constant, an agent with a rationality score 8 extracts resources faster than a level 4 agent. The resources that are extracted by the agents become their wealth to keep. For example, an agent with a rationality score 2 accumulates wealth slower than an agent with a score of 6 (assuming all the other variables in the model are held constant). Therefore, it is expected that agents with higher level of rationality would extract more resources and in return accumulate more wealth.

Once the simulation is set into motion, the agents start generating wealth depending on their level of rationality. It is expected that the agents with higher levels of rationality collect wealth faster than the ones with lower

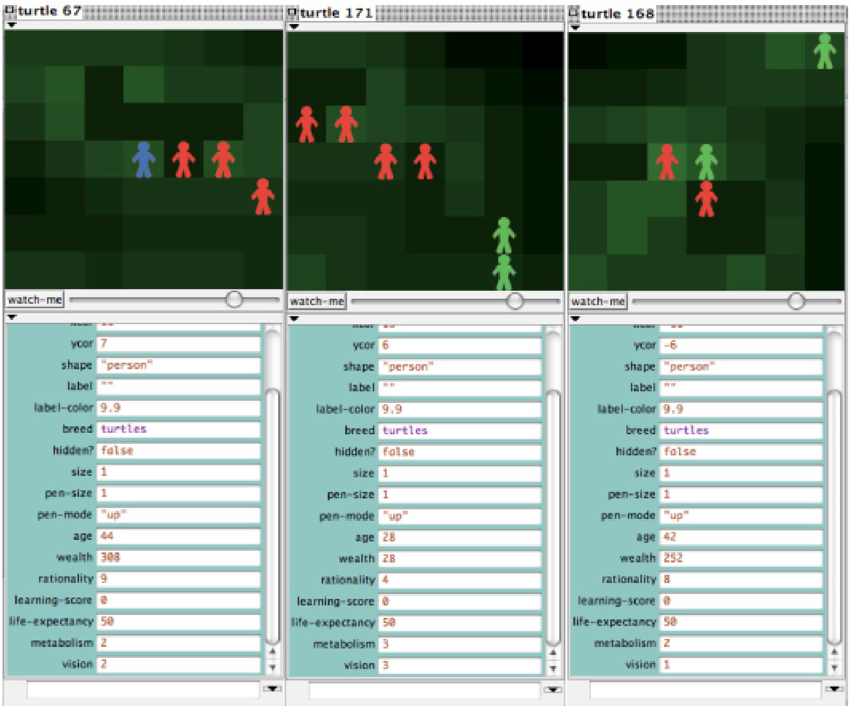
Figure 1. The Basic Rationality Model.



levels. After running the model for some time, the simulation generates three agent types in terms of their level of wealth as it can be seen from the right-hand side picture of Figure 1. The red agents represent the lowest level of wealth generated, and then the green agents represent medium level of wealth. Lastly, the highest wealth level compared to the wealth generated by the other agents is represented with blue agents. Figure 2 depicts samples, one from each of these agent types. For instance, the left-hand side picture provides information for turtle 67, which is the blue agent in the center of the left-hand side display. When compared with the information of turtle 171 and turtle 168, turtle 67 has generated much more wealth. Turtle 67's level of rationality is 9, which is followed by turtle 168 with a rationality score 8 and turtle 171 with level of rationality 4. Therefore, there is a relationship between the agents' level of rationality and the amount of wealth that they generated.

However, random factors are also included into the modeling that would prevent the relationship between rationality and wealth generation to be absolute. Besides the level of rationality, the agents have random levels of vision and metabolism. The vision defines how many grids away an agent can see in the virtual environment. Therefore, agents with a higher level of vision have a higher chance to locate resource rich spots. Additionally, agents have random metabolism levels. At every move, agents have to burn some level of wealth. Agents with higher level of metabolism are burning more wealth compared to the others. Therefore, the lower the level of metabolism, the higher the probability to survive and to accumulate wealth. Furthermore, the location where the agent is created at the beginning of the simulation

Figure 2. Inspect Turtle



is crucial. As it is mentioned earlier, when the model is set up, the agents are randomly distributed on the simulation environment. Some of them are created on the resource mountains or close to them, but some of the agents fall far away from the resources. The agents that are created away from the resources are going to be disadvantaged, and they are less likely to surpass the wealth levels of the ones that were created on the resources. Thus, vision, metabolism, and location represent random factors that can influence the basic functioning principle of the model. As a result, due to these random factors, not all agents with high levels of rationality will be able to collect relatively high levels of wealth. Similarly, because of these random factors, some of the agents with low levels of rationality will be able to collect more wealth than expected.

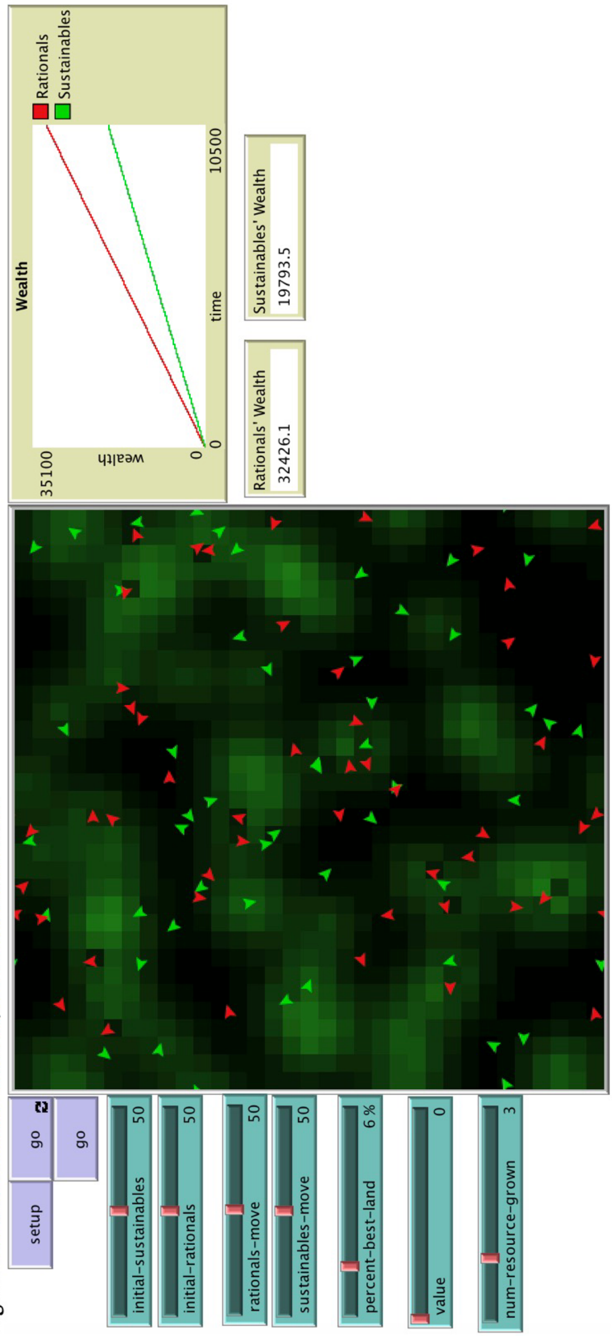
By adding new variables and behavioral patterns the representation of the models are strengthened. The second model in the analysis introduces one more breed of agents – in the Two Breed Model. The Basic Rationality Model portrayed the fundamental logic of rationality. However, this foundational model needs to be developed with new variables and concepts. Therefore, in addition to the rational mindset, the Two Breed Model depicts the sustainable mentality. By making additions to the basic model the core functioning principle of the model is being tested as well. Because when new variables or behavior patterns are introduced in the model, the core mechanism and functioning principle should be able to accommodate this situation. Furthermore, testing and model development increase the capacity of the model to capture real phenomena.

In the Two Breed Model, rationality scale is divided into two. Agents that are randomly scored from 1 to 5 are called sustainables; on the other hand, agents that have rationality scores between 6 to 10 are called rationals. The rationality scores of rationals are higher than sustainables to reflect their desire to extract resources for the sake of their immediate interests. The rationality score of sustainables is lower to depict how they curb their consumption to maximize long-term gains. Sustainables are represented by green and rationals are represented by red color.

As it can be seen from Figure 3, by utilizing the sliders on the left-hand side of the simulation screen, certain parameters in the model can be manipulated. For example, the first two sliders, which are initial-sustainables and initial-rationals, are designed to control the population of the agents. Additionally, agents' movement can be manipulated via the sliders rationals-move and sustainables-move. The sliders related to movement are useful in terms of comparing the activity and the mobility levels of different breeds. Furthermore, the resource quantity can be manipulated through percent-best-land and num-resource-grown. More specifically, percent-best-land slider is for changing the resource richness in the environment – the higher the percent-best-land, the more abundant the resources in the simulation environment. On the other hand, num-resource-grown operates the growth or regeneration level of the resources after being consumed by the agents – the lower the num-resource-grown, the more time it takes to restore the resources in the simulation environment. The plot view shows the mean wealth of the breeds. Underneath the plot screen there are two monitors displaying the mean calculations of sustainables and rationals.

Model controls are critical to simulating real life phenomena. For example, take a communal forest and woodsmen who make living from this natural resource. The woodsmen in this environment are composed of individuals with rational or sustainable mindsets each to varying degrees. The woodsmen population can be controlled through the sliders of initial-sustainables and initial-rationals (Figure 3). Their activity in the forest can

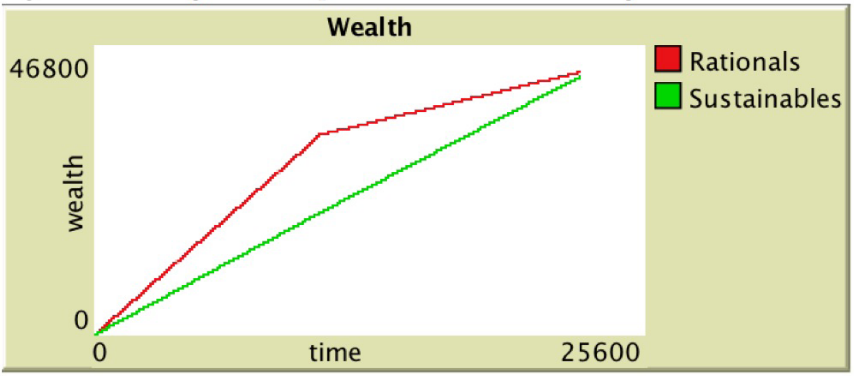
Figure 3. Rationals vs. Sustainables, the Two Breed Model.



be managed by the sliders of rationals-move and sustainables-move. Forest vegetation density can be manipulated by percent-best-land. The regrowth rate of the forest after being cut down can be controlled by num-resource-grown. These controls can be applied to other common-pooled resources like fisheries, grazing lands, irrigation systems or groundwater basins.

The Two Breed Model clearly demonstrates the wealth difference between sustainables and rationals. With the assumption of constant grow-back in resources, the rational agents accumulate more resources than sustainable agents – the more the simulation is run, the more the wealth gap opens between the two breeds. Even if the movement frequency of rationals is decreased and sustainables' increased, rational agents generate more wealth due to their will to extract resources faster (assuming the resource level is constant). The mean wealth of sustainables can catch rationals' (Figure 4) only when the movement of sustainables is increased to above 90% levels and movement of rationals is stopped (only extracting resources from where they are), and the resource growback level (num-resource-grown) is minimized to level 1. In other words, the wealth gap between the two breeds can only be closed if rationals stop seeking out resources and only extract from where they are while sustainables increase their activity level to find resources.

Figure 4. Wealth generation speed of rationals is decreasing.



Model development and testing continues with introducing new behavioral patterns. After presenting the second breed, further experimentation was conducted to reflect behavioral patterns of people or societies. In the third model, which is named as the Scanning and Localizing Model, rational agents are constantly looking for resources to extract; therefore, they have a behavioral rule to constantly scan the environment. On the other hand, sustainable agents have a behavioral rule to turn towards the closest resource mountain and continue extracting around that mountain throughout their life cycles without seeking other resources. As it can be seen from Figure 5, while rationals are scattered around the environment looking for resources, sustainables are extracting locally; green groups are on the resource mountains while red agents are scattered around the environment. The graph that calculates means tells us that with these behavior patterns, sustainables' wealth generation capacity increases—the mean wealth of sustainables is running close to the mean wealth of rationals compared to the mean gap in the Two Breed Model.

In this behavioral model, the amount of resources in the environment defines the winners and the losers. As Figure 5 displays, current percent-best-land of the model is 5%. What if the percent-best-land is decreased below 5%? Figure 6 demonstrates what would happen to these agents in a scenario of decreasing resources. The agents that are satisfied with the resources of a certain region generate more wealth compared to the agents that constantly look for resources to extract.

One more behavior type can be tested in this model. As it can be seen from Figure 5, the slider named 'value' was adjusted as 0 in the previous test. This slider inserts a variable to the simulation, which is designed to demonstrate the wealth generation effect when agents sacrifice from their wealth towards the resource. The purpose of this variable is to represent people who would invest or sacrifice from their wealth towards the activity that makes their living. For instance, the income generating capacity of a farmer who spends some of his annual income towards maintaining the fertility of his land can be demonstrated in this model. The 'value' variable becomes active when it is plugged in to the extract code of the model.[33] This variable is only applied to sustainables because this behavior pattern was thought to be more prevalent among people who make their livings by environmental means, such as farming or fishing. When the 'value' variable starts functioning, sustainable agents start sacrificing some of the resources that they extract from the environment back to its origin rather than transforming it into personal wealth. For example, if the 'value' slider is adjusted to 50%, then the sustainable agents will start extracting only with half of their extracting capacity. A sustainable with a rationality score 4 will start extracting level 2 instead of a 4, leaving half of what it can extract at the resource.

When experimented with the 'value' variable, the first impact was a clear fall in the overall wealth generated by sustainables. However, this behavioral pattern proved to be important when resource-growth-interval and percent-best-land is very low. In such a scenario, the sacrificing behavior of sustainables keeps this breed alive longer than rationals. In other words, when there are scarce resources, due to the sacrificing behavior, sustainables survive longer than rationals.

The final variable that will be presented in the analysis is called 'greed'. In this version of the model, a new behavioral pattern related to the rational agents will be tested. As it was mentioned earlier, rationals already have higher levels of rationality scores in the models to reflect their higher desire to extract resources for the sake of maximizing their immediate interests. However, what would happen if we could manipulate the expectation level of rationals? This is actually possible with a small twist in the code. In this version of the model both breeds have a simple but very efficient rule to calculate and locate the best resource amount around them. The code group that lets the agents behave with this rule is called 'turn-toward-resource'. Every agent looks to four directions (north, east, south, and west) and makes a simple calculation comparing all the resource levels in those directions - including the spot that each one is standing at - and gives a decision to move or not to move towards the best resource. By inserting a variable in the turn-toward-resource code of rationals, it is possible to define the minimum resource units that these agents are looking for. In other words, the higher the level of greed, the higher the resource level that rationals will be looking for. The maximum resource level (max-resource) in one patch is adjusted in the code as 50. When the greed level is increased over 50 (higher than the maximum resource level set in the model), we observe a scanning behavior from the rationals – not stopping on any resource mountain but constantly scanning the environment. Because no resource mountain is satisfactory for them to stop by; they just extract from the resources on their ways. However, the more we decrease the level of greed, the more we observe rational agents settling down in resource mountains. This behavior pattern with greed directly influences the resource extraction and wealth generation of rationals. It is observed that some level of greed helps rational agents to generate wealth efficiently; however, when a certain threshold of greed is passed, rational agents lose their resource extraction efficiency. As it can be seen from Figure 7, when greed level is adjusted to 30, rationals' resource generation competence falls behind sustainables' wealth generation capability.

The Greed Model is tested in BehaviorSpace to understand the influence

Figure 5. The Scanning and Localizing Model.

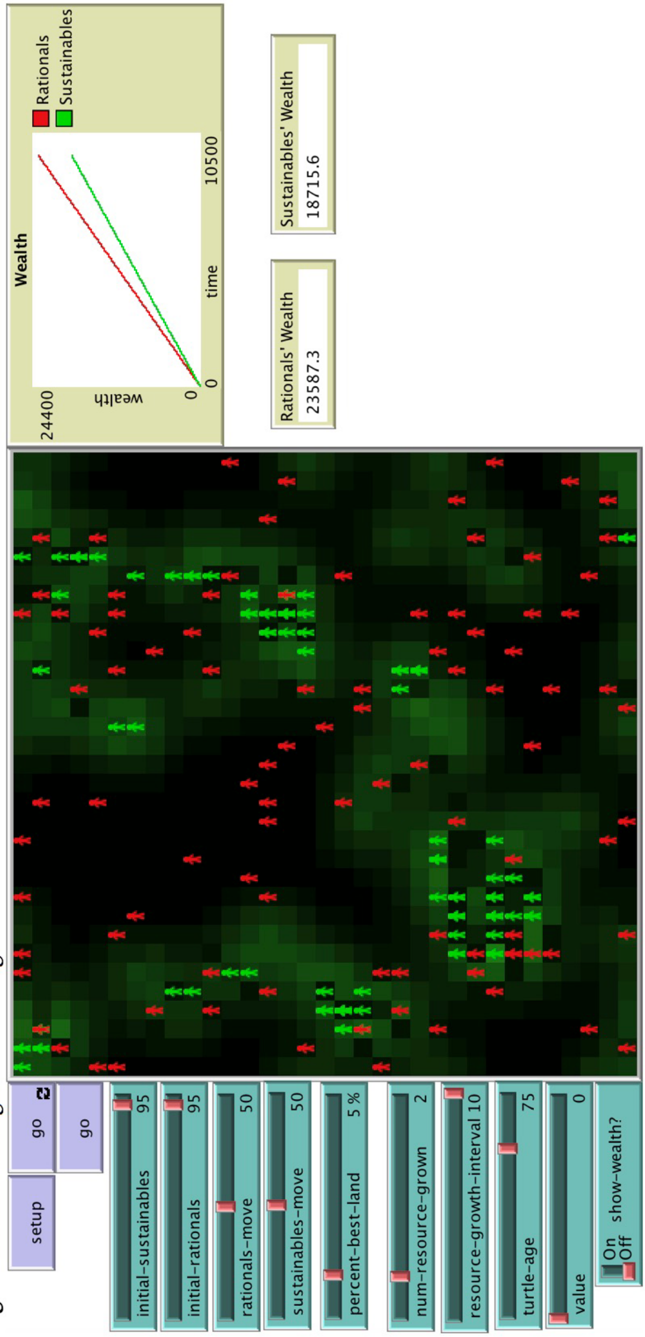
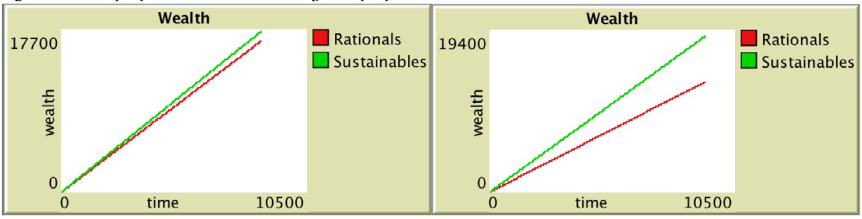


Figure 6. Left Graph: percent-best-land at 4%; Right Graph: percent-best-land at 3%.



of greed with other factors. The following parameters are inserted to BehaviorSpace in NetLogo for experimentation:

INITIAL-SUSTAINABLES: 100
INITIAL-RATIONALS: 100
RATIONALS-MOVE: 50
SUSTAINABLES-MOVE: 50
NUM-RESOURCE-GROWN: 1, 5, 10
GREED: 1, 50, 100
PERCENT-BEST-LAND: 1, 3, 5
RESOURCE-GROWTH-INTERVAL: 1, 5, 10

To test the combination of all these parameters, BehaviorSpace runs slightly more than 800 simulations. The analysis output is presented in Table 2, Graph 1, Graph 2, and Graph 3. The results display the percent-best-land level of 1 under the categories of greed 1, 50, and 100. In Table 2, rows show three different levels of resource-growth-interval under the categories of greed. The columns exhibit number-resource-grown.

Every greed category on Table 2 is separately illustrated in the following graphs. Additionally, in the Appendix section, the greed categories are presented under the percent-best-land levels of 3 and 5 for further information. The data parameters are all embedded in the graphs. As demonstrated in Graph 1, there are three variables laid out in the x-axis. The very top layer indicates the number of resources grown, which depicts the levels of 1, 5 and 10. In the middle layer, resource growth interval is shown. The bottom layer is percent best land. For instance, Graph 1 tells us that when greed level is 1 and percent-best-land level is 1, sustainables end up with slightly more wealth except in conditions where number-of-resource-grown is very low.

The results of the BehaviorSpace experiments that are exhibited through Graph 1 and Graph 3, and through Graph 1a and Graph 3b in the Appendix section demonstrate that greed and percent-best-land are critical factors affecting the wealth generation capacity of the agents. According to the

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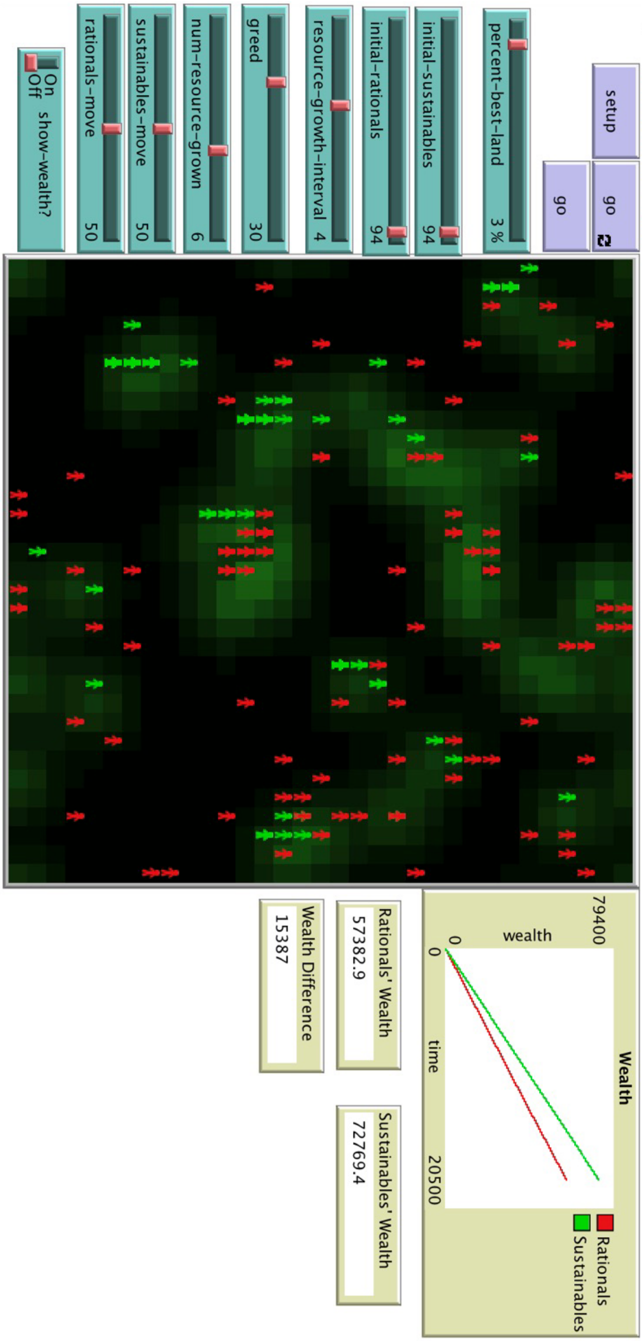
Table 2. Average of mean wealth, percent-best-land = 1

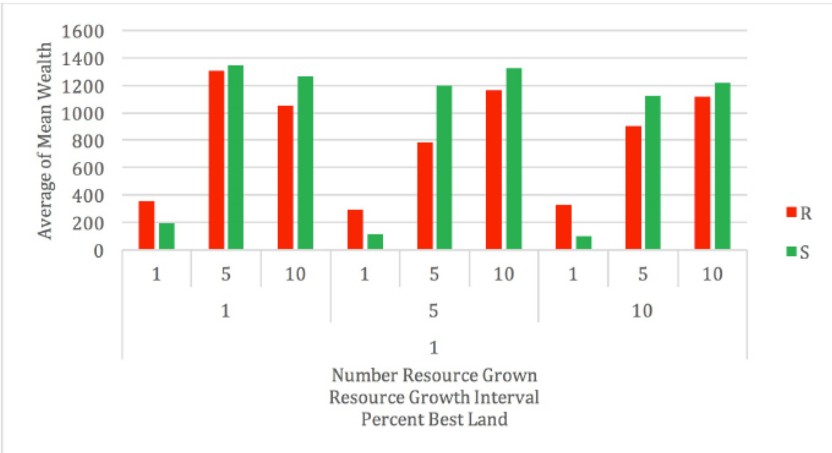
Number Resource Grown		1		5		10	
		R	S	R	S	R	S
Greed Level 1							
	1	354	196	1303	1343	1052	1266
Resource Growth Interval	5	296	115	781	1196	1166	1326
	10	325	100	904	1126	1120	1217
Greed Level 50							
	1	299	207	342	1542	363	1440
Resource Growth Interval	5	200	114	391	1353	312	1561
	10	238	158	295	1196	261	1393
Greed Level 100							
	1	257	198	310	1667	361	1617
Resource Growth Interval	5	212	126	312	1126	379	1646
	10	174	95	322	1187	359	1607

R: rational agents
S: sustainable agents

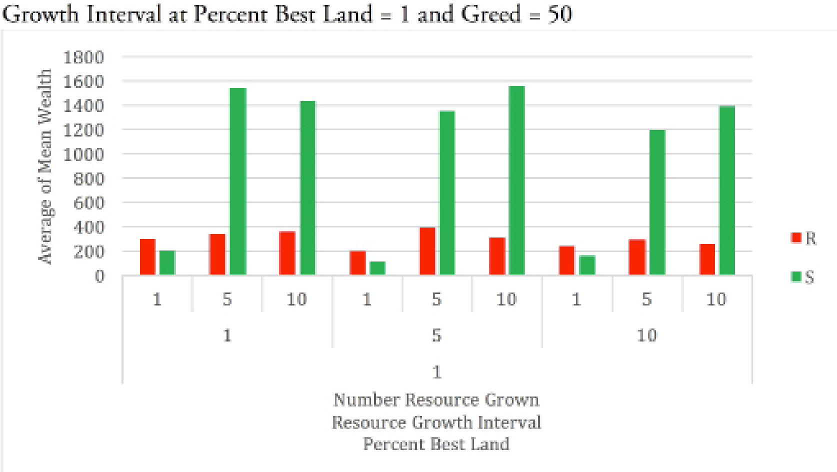
Figure 7. The Greed Model.



Graph 1. Wealth of Rationals vs Sustainables: Number Resource Grown and Resource Growth Interval at Percent Best Land = 1 and Greed = 1



Graph 2. Wealth of Rationals vs Sustainables: Number Resource Grown and Resource Growth Interval at Percent Best Land = 1 and Greed = 50



graphical demonstrations, rational agents manage to generate more wealth in resource abundant scenarios. However, when the greed level of rational actors is increased to 50, which is depicted in Graphs 2, 2a and 2b, the wealth generating capability of rational actors falter. Unless percent-best-land is very high (level 5), sustainable agents generate more wealth than rational actors when the greed level is set to 50.

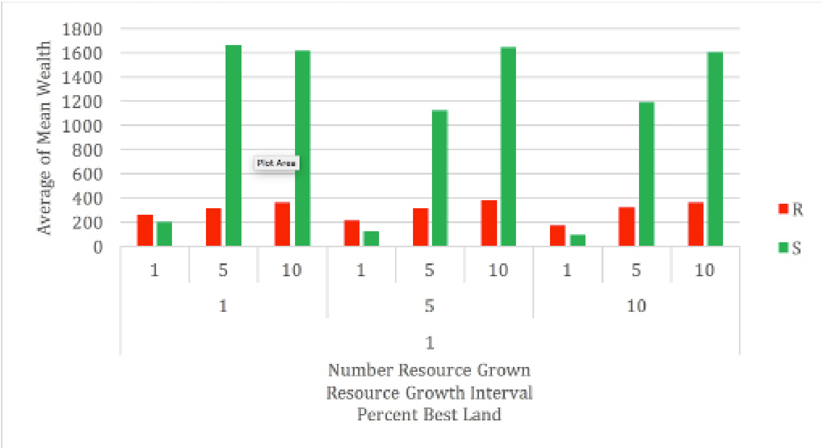
Similarly, when the greed level is increased to 100, rational agents lose their wealth generating capacities even further (Graphs 3, 3a, and 3b). Even in resource rich scenarios (percent-best-land=5), if the greed level is at high levels, sustainable agents generate more wealth than rational agents. Compared to the other variables, resource-growth-interval is a weak factor with regard to comparing the two mindsets. Consequently, the higher the level of greed, the lower the agents' capacity to generate wealth.

The BehaviorSpace experiment results, portrayed through Graph 1 and Graph 3, and Graph 1-a through Graph 3-b tell us that when agents only seek to maximize self-interest and act individualistic, they actually end up being worse off. There might be environmental conditions where instead of being rational, having a sustainable mindset (being concerned about the nature and resource depletion) will be more helpful to agents in terms of generating wealth. In order to compare the performance of the two mindsets, the BehaviorSpace experiment data can be arranged in a way to represent an environmental degradation setting.

Let's assume a scenario of resource depletion in the world. It is the year around 2117. Due to climate change and pollution, there is little clean water, air and soil resources. Degradation of environment and destruction of ecosystem have limited the agricultural output in the world. As a result, in such a scenario, people would face scarce resources - environmental limitations. The BehaviorSpace test results are presented from high percent-best-land towards lower percentages to create the impact of these environmental conditions. The experimental data helps us understand the survival capacity of the agents with rational mindset compared to the ones with sustainable mindset.

Graph 4 compares the wealth levels of rationals and sustainables under depleting resources. The x-axis displays three layers of variables: the first layer is number- resources-grown; the middle layer is percent-best-land; and there is greed at the bottom. From the left towards the right-hand side of the graph, number-resources-grown and percent-best-land decreases. In the left portion of the graph, under greed level 1, rationals gather more wealth when the resources are rich (number-resource-grown=10, percent-best-land=5 or 3).

Graph 3. Wealth of Rationals vs Sustainables - Number Resource Grown and Resource Growth Interval at Percent Best Land = 1 and Greed = 100



Graph 4. Wealth of Rationals vs Sustainables - Number Resource Grown = 10, Resource Growth Interval = 1, Percent Best Land, and Greed

When the number-resource-grown falls to 5, sustainables always generate more resources. However, both rationals' and sustainables' wealth drop significantly when number-resource-grown falls to 1. In the middle portion of Graph 4, which presents the results under the greed level 50, the overall wealth generation capability of rationals decrease compared to level 1 greed. Under the greed level 100, rationals lose their wealth generation capability even further. Rising expectations too much in terms of resource extraction turns out to be a negative trait for wealth generation. In the most extreme resource depletion case, where both number-resource-grown and percent-best-land are at level 1, rationals accumulate slightly more wealth compared to sustainables; however, both breeds can accumulate only little wealth that they are equally on the verge of perishing.

The experimentation data indicate that in a resource depletion scenario, the rational mindset does not always bring the highest level of utility. Graph 4 presents 27 different environmental and behavioral combinations to enact different cases. The rational mindset generates more wealth only in 12 of these cases. On the other hand, the sustainable mindset produces more wealth in 15 of these cases. On the left-hand side of the graph, it is observed that rational agents obtain high yields when there are abundant resources. However, once the resources start to deplete, sustainable agents begin surpassing rational agents in terms of wealth. On the right-hand side of the graph where the greed level is the highest, sustainable agents increase the wealth gap with rational agents. The sustainable mindset generates steady wealth throughout the cases compared to the rational mindset. The wealth generation capability of the rational agents become unstable due to greed and environmental conditions. All in all, in a scenario of resource depletion, the likelihood of survival decreases for rational agents when their level of greed increases.

Conclusion

This paper tested the basic understanding of rationality in a simulation environment by utilizing agent-based modeling and introduced sustainability as an advancement.

Rationality is considered as the central pillar of decision-making models, and at the same time rationality has been defined in different ways throughout the literature. Through simulation modeling, this study isolated specific elements of this complex concept and explored basic notions of rationality. The rational mindset, based on Hardin's tragedy of the commons model portraying the individualistic and self-interest seeking behavior, is compared with sustainable mindset. The sustainable mindset acknowledges the limitations of environmental resources and act accordingly. While simulation modeling is a methodological tool, it has the potential to design and represent real-life phenomenon. Thus, the results from these models are compelling and have potential to contribute to the understanding of rationality.

The various model results indicate that the rational mindset does not always guarantee maximum utility. The simulation data reveal that rational agents struggle generating wealth when environmental factors are manipulated. Under the conditions of limited resources, the sustainable agents proved to be more resilient. When the greed factor is introduced in the simulation, the rational agents are further incapacitated to generate wealth. Consequently, in a scenario of resource depletion, the chances of survival decrease for the rational agents, and greed ends up aggravating their resource extraction capability. Conversely, sustainable agents are capable of generating steady wealth even if the environmental conditions are pressing.

Sustainability is not an alternative mindset to rationality, but a development to it. A rational actor adapts to environmental boundaries in order to minimize losses and maximize benefits. If an actor insists on preserving an individualistic and self-interested mindset under conditions of resource depletion, his wealth generation capability will be weakened and his survival chances will decrease. A rational actor must adopt a sustainable mindset when faced with environmental deterioration to increase the level of utility and likelihood of survival under the new conditions.

Notes

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3 Damian Carrington, "Earth Has Lost Half of Its Wildlife in the Past 40 Years, Says WWF," The Guardian, September 30, 2014, sec. Environment, para. 7.

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6 Uri Wilensky, NetLogo (Evanston, IL: Center for Connected Learning and Computer-Based Modeling, Northwestern University, 1999), http://ccl.northwestern.edu/netlogo/index.shtml.

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9 Frank C. Zagare, "Rationality and Deterrence," World Politics 42, no. 2 (January 1, 1990): 239, doi:10.2307/2010465.

10 Herbert A. Simon, "From Substantive to Procedural Rationality," in Method and Appraisal in Economics, ed. Spiro Latsis (Cambridge?; New York: Cambridge University Press, 1976).

11 R. Duncan Luce and Howard Raiffa, Games and Decisions: Introduction and Critical Survey (New York: Wiley, 1957), 50; Zagare, "Rationality and Deterrence."

12 Herbert A. Simon, "A Behavioral Model of Rational Choice," The Quarterly Journal of Economics 69, no. 1 (February 1, 1955): 99–118, doi:10.2307/1884852; Herbert A. Simon, "Theories of Bounded Rationality," in Decision and Organization: A Volume in Honor of Jacob Marschak, ed. Jacob Marschak et al., Studies in Mathematical and Managerial Economics, v. 12 (Amsterdam: North-Holland Pub. Co, 1972); Herbert A. Simon, "Bounded Rationality and Organizational Learning," Organization Science 2, no. 1 (February 1, 1991): 125–34, doi:10.1287/orsc.2.1.125.

13 Garrett Hardin, "The Tragedy of the Commons," Science 162, no. 3859 (December 13, 1968): 1243–48, doi:10.1126/science.162.3859.1243.

14 Ibid., 1244.

15 Hardin, "The Tragedy of the Commons."

16 Richard Campbell, "Background for the Uninitiated," in Paradoxes of Rationality and Cooperation: Prisoner's Dilemma and Newcomb's Problem, ed. Richmond Campbell and Lanning Snowden (Vancouver: University of British Columbia Press, 1985); Albert W. Tucker, "The Mathematics of Tucker: A Sampler," The Two-Year College Mathematics Journal 14, no. 3 (1983): 228–32, doi:10.2307/3027092.

17 Olson, The Logic of Collective Action, 1–2.

18 Ibid., 2.

19 Ibid., 7.

20 Elinor. Ostrom, Governing the Commons: The Evolution of Institutions for Collective Action (Cambridge; New York: Cambridge University Press, 1990), 7–21.

21 Tim Forsyth and Craig Johnson, "Elinor Ostrom's Legacy: Governing the Commons and the Rational Choice Controversy," Development and Change 45, no. 5 (September 1, 2014): 1093–1110, doi:10.1111/dech.12110.

22 Ostrom, Governing the Commons, 1.

23 Ibid.

24 Larry L. Kiser and Elinor Ostrom, "The Three Worlds of Action: A Metatheoretical Synthesis of Institutional Approaches," in Strategies of Political Inquiry, ed. Elinor Ostrom, Sage Focus Editions 48 (Beverly Hills: Sage Publications, 1982), 218.

25 Ostrom, Governing the Commons, xi.

26 Ibid., 43.

27 Ibid., 90.

28 Hardin, "The Tragedy of the Commons."

29 Forsyth and Johnson, "Elinor Ostrom's Legacy," 1098.

30 G. Gilbert, Agent-Based Models (Los Angeles: Sage Publications, 2008), 1–10.

31 Hardin, "The Tragedy of the Commons."

32 Justin Li and Uri Wilensky, NetLogo Sugarscape 1 Immediate Growback Model (Evanston, IL: Center for Connected Learning and Computer-Based Modeling, Northwestern University, 2009), http://ccl.northwestern.edu/netlogo/models/Sugarscape1ImmediateGrowback; Uri Wilensky, NetLogo Wealth Distribution Model (Evanston, IL: Center for Connected Learning and Computer-Based Modeling, Northwestern University, 1998), http://ccl.northwestern.edu/netlogo/models/WealthDistribution.

33 The code related to Scanning and Localizing Model is listed under the C section of Appendix I. When the semicolons in front of the codes containing the 'value' variable are removed and the parentheses in the initial code are deleted, the 'value' algorithm starts functioning.

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Appendix I — Codes

A – The NetLogo Code for the Basic Rationality Model

```
GLOBALS
[
  MAX-RESOURCE
]

PATCHES-OWN
[
  RESOURCE-HERE
  MAX-RESOURCE-HERE
]

TURTLES-OWN
[
  AGE
  WEALTH
  RATIONALITY
  LEARNING-SCORE
  LIFE-EXPECTANCY
  METABOLISM
  VISION
]

TO SETUP
  CA
  SET MAX-RESOURCE 50
  SETUP-PATCHES
  SETUP-TURTLES
  RESET-TICKS
END

TO SETUP-PATCHES
  ASK PATCHES
  [SET MAX-RESOURCE-HERE 0
    IF ( RANDOM-FLOAT 100.0) <= PERCENT-BEST-LAND
    [ SET MAX-RESOURCE-HERE MAX-RESOURCE
      SET RESOURCE-HERE MAX-RESOURCE-HERE ]]

  REPEAT 5
  [ ASK PATCHES WITH [MAX-RESOURCE-HERE != 0]
    [ SET RESOURCE-HERE MAX-RESOURCE-HERE ]
```

```
  DIFFUSE RESOURCE-HERE 0.25 ]

  REPEAT 10
  [ DIFFUSE RESOURCE-HERE 0.25 ]
  ASK PATCHES
  [ SET RESOURCE-HERE FLOOR RESOURCE-HERE
    SET MAX-RESOURCE-HERE RESOURCE-HERE
    RECOLOR-PATCH ]
END

TO RECOLOR-PATCH
  SET PCOLOR SCALE-COLOR GREEN RESOURCE-HERE 0 MAX-RESOURCE
END

TO SETUP-TURTLES
  SET-DEFAULT-SHAPE TURTLES "PERSON"
   CRT NUM-PEOPLE
   [ MOVE-TO ONE-OF PATCHES
    SET SIZE 1.0
    SET-TURTLE-INITIAL
    SET AGE RANDOM LIFE-EXPECTANCY ]
  RECOLOR-TURTLES
END

TO SET-TURTLE-INITIAL
  SET AGE 0
  FACE ONE-OF NEIGHBORS4
  SET LIFE-EXPECTANCY LIFE-EXPECTANCY-MIN +
  RANDOM (LIFE-EXPECTANCY-MAX - LIFE-EXPECTANCY-MIN + 1)
  SET METABOLISM 1 + RANDOM METABOLISM-MAX
  SET WEALTH 0
  SET VISION 1 + RANDOM MAX-VISION
  SET RATIONALITY RANDOM-IN-RANGE 1 10
END

TO RECOLOR-TURTLES
  LET MAX-WEALTH MAX [WEALTH] OF TURTLES
  ASK TURTLES
  [ IFELSE (WEALTH <= MAX-WEALTH / 3)
  [ SET COLOR RED ]
  [ IFELSE (WEALTH <= (MAX-WEALTH * 2 / 3 ))
  [ SET COLOR GREEN ]
```

```
  [ SET COLOR BLUE ] ] ]
END

TO GO
  ASK TURTLES
  [ TURN-TOWARDS-RESOURCE ]
  ;;VISION
  EXTRACT
  ASK TURTLES
  [ MOVE-AGE-DIE ]
  RECOLOR-TURTLES
  IF TICKS MOD RESOURCE-GROWTH-INTERVAL = 0
  [ ASK PATCHES [ GROW-RESOURCE ] ]
  TICK
END

TO TURN-TOWARDS-RESOURCE
  SET HEADING 0
  LET BEST-DIRECTION 0
  LET BEST-AMOUNT RESOURCE-AHEAD
  SET HEADING 90
  IF ( RESOURCE-AHEAD > BEST-AMOUNT )
  [ SET BEST-DIRECTION 90
  SET BEST-AMOUNT RESOURCE-AHEAD ]
  SET HEADING 180
  IF (RESOURCE-AHEAD > BEST-AMOUNT )
  [ SET BEST-DIRECTION 180
  SET BEST-AMOUNT RESOURCE-AHEAD ]
  SET HEADING 270
  IF ( RESOURCE-AHEAD > BEST-AMOUNT)
  [ SET BEST-DIRECTION 270
    SET BEST-AMOUNT RESOURCE-AHEAD ]
  SET HEADING BEST-DIRECTION
END

TO-REPORT RESOURCE-AHEAD
  LET TOTAL 0
  LET HOW-FAR 1
  REPEAT VISION
  [ SET TOTAL TOTAL + [RESOURCE-HERE] OF PATCH-AHEAD HOW-FAR
  SET HOW-FAR HOW-FAR + 1 ]
  REPORT TOTAL
```

```
END

TO GROW-RESOURCE
  IF (RESOURCE-HERE < MAX-RESOURCE-HERE)
  [ SET RESOURCE-HERE RESOURCE-HERE + NUM-RESOURCE-GROWN
  IF (RESOURCE-HERE > MAX-RESOURCE-HERE)
  [ SET RESOURCE-HERE MAX-RESOURCE-HERE ]
  RECOLOR-PATCH ]
END

TO EXTRACT
  ASK TURTLES
  [ SET WEALTH FLOOR (WEALTH + RATIONALITY)]
  ASK TURTLES
  [ SET RESOURCE-HERE (RESOURCE-HERE - RATIONALITY)
  RECOLOR-PATCH]
  ASK TURTLES
  [ IF (RESOURCE-HERE < RATIONALITY) [SET RESOURCE-HERE 0]
   SET WEALTH (WEALTH + RESOURCE-HERE)
   RECOLOR-PATCH]
END

TO MOVE-AGE-DIE
  FD 1
  SET WEALTH (WEALTH - METABOLISM)
  SET AGE (AGE + 1)
  IF (WEALTH < 0) OR (AGE >= LIFE-EXPECTANCY)
   [SET-TURTLE-INITIAL]
END

TO-REPORT RANDOM-IN-RANGE [LOW HIGH]
  REPORT LOW + RANDOM (HIGH - LOW + 1)
END
```

B – The NetLogo Code for the Two Breed Model

```
GLOBALS [ RESOURCE MAX-RESOURCE MIN-RESOURCE ]

BREED [ SUSTAINABLES SUSTAINABLE ]
BREED [ RATIONALS RATIONAL ]
TURTLES-OWN [ METABOLISM VISION RATIONALITY WEALTH ]
```

```
patches-own [ resource-here max-resource-here ]


to setup
  ca
  set max-resource 50
  set min-resource 0
  setup-patches
  setup-turtles
  reset-ticks
end

to setup-patches
  ask patches
  [ set max-resource-here 0
    if ( random-float 100.0 ) <= percent-best-land
    [ set max-resource-here max-resource
      set resource-here max-resource-here ]]

  repeat 5
  [ ask patches with [ max-resource-here != 0 ]
    [ set resource-here max-resource-here ]
    diffuse resource-here 0.25 ]

  repeat 10
  [ diffuse resource-here 0.25 ]
  ask patches
  [ set resource-here floor resource-here
    set max-resource-here resource-here
    recolor-patch ]
end

to recolor-patch ;; WD
  set pcolor scale-color green resource-here 0 max-resource
end


to setup-turtles
  create-sustainables initial-sustainables [
  set color 65
  setxy random-xcor random-ycor
  set rationality random 4 + 1
```

```
  ]
  CREATE-RATIONALS INITIAL-RATIONALS [
  SET COLOR RED
  SETXY RANDOM-XCOR RANDOM-YCOR
  SET RATIONALITY RANDOM 5 + 5
  ]
END

TO GO
  ASK RATIONALS
  [ IF (CEILING RANDOM-FLOAT 100.0)<= RATIONALS-MOVE [FD 1 ] ]
  ASK SUSTAINABLES;;
  [ IF (CEILING RANDOM-FLOAT 100.0)<= SUSTAINABLES-MOVE [FD 1] ]
  EXTRACT
  ASK PATCHES [ GROW-RESOURCE ]
  TICK
END

TO EXTRACT

   ASK RATIONALS [
    IFELSE RESOURCE-HERE > 0 AND RESOURCE-HERE >= RATIONALITY
    [ SET WEALTH FLOOR ( WEALTH + RATIONALITY )]
    [ SET WEALTH FLOOR ( WEALTH + RESOURCE-HERE ) ] RECOLOR-PATCH]
  ASK RATIONALS [
  IFELSE RESOURCE-HERE > 0 AND RESOURCE-HERE >= RATIONALITY
  [ SET RESOURCE-HERE FLOOR ( RESOURCE-HERE - RATIONALITY )]
  [ SET RESOURCE-HERE 0 ] RECOLOR-PATCH]

  ASK SUSTAINABLES [
    IFELSE RESOURCE-HERE > 0 AND RESOURCE-HERE >= RATIONALITY
    [ SET WEALTH FLOOR ( WEALTH + (RATIONALITY - RATIONALITY * (VALUE
/ 100))) ]
    [SET WEALTH FLOOR ( WEALTH + RESOURCE-HERE )] RECOLOR-PATCH ]

  ASK SUSTAINABLES [
  IFELSE RESOURCE-HERE > 0 AND RESOURCE-HERE >= RATIONALITY
    [ SET RESOURCE-HERE FLOOR ( RESOURCE-HERE - (RATIONALITY -
RATIONALITY * (VALUE / 100 ))) ]
  [ SET RESOURCE-HERE 0 ] RECOLOR-PATCH]

END
```

```
TO GROW-RESOURCE
  IF ( RESOURCE-HERE < MAX-RESOURCE-HERE )
  [ SET RESOURCE-HERE RESOURCE-HERE + NUM-RESOURCE-GROWN
  IF ( RESOURCE-HERE > MAX-RESOURCE-HERE )
  [ SET RESOURCE-HERE MAX-RESOURCE-HERE ]
  RECOLOR-PATCH ]
END
```

C – The NetLogo Code for the Scanning and Localizing Model

```
GLOBALS [ RESOURCE MAX-RESOURCE MIN-RESOURCE INITIAL-WEALTH ]

BREED [ SUSTAINABLES SUSTAINABLE ]
BREED [ RATIONALS RATIONAL ]
TURTLES-OWN [ METABOLISM VISION RATIONALITY WEALTH AGE MAX-AGE]
PATCHES-OWN [ RESOURCE-HERE MAX-RESOURCE-HERE ]


TO SETUP
  CA
  SET MAX-RESOURCE 50
  SETUP-PATCHES
  SETUP-TURTLES
  RESET-TICKS
END

TO SETUP-PATCHES
   ASK PATCHES
  [ SET MAX-RESOURCE-HERE 0
    IF ( RANDOM-FLOAT 100.0 ) <= PERCENT-BEST-LAND
    [ SET MAX-RESOURCE-HERE MAX-RESOURCE
      SET RESOURCE-HERE MAX-RESOURCE-HERE ]]

  REPEAT 5
  [ ASK PATCHES WITH [ MAX-RESOURCE-HERE != 0 ]
    [ SET RESOURCE-HERE MAX-RESOURCE-HERE ]
    DIFFUSE RESOURCE-HERE 0.25 ]

  REPEAT 10
```

```
  [ DIFFUSE RESOURCE-HERE 0.25 ]
  ASK PATCHES
  [ SET RESOURCE-HERE FLOOR RESOURCE-HERE
    SET MAX-RESOURCE-HERE RESOURCE-HERE
    RECOLOR-PATCH ]
END

TO RECOLOR-PATCH
  SET PCOLOR SCALE-COLOR GREEN RESOURCE-HERE 0 MAX-RESOURCE
END

TO SETUP-TURTLES
  CREATE-SUSTAINABLES INITIAL-SUSTAINABLES
  [
    MOVE-TO ONE-OF PATCHES
    SET COLOR 65
    SET SHAPE "PERSON"
    ;;SETXY RANDOM-XCOR RANDOM-YCOR
    SET-INITIAL-TURTLE-VARS
    SET RATIONALITY RANDOM 4 + 1 ]
  CREATE-RATIONALS INITIAL-RATIONALS
  [
    MOVE-TO ONE-OF PATCHES
    SET COLOR RED
    SET SHAPE "PERSON"
    ;;SETXY RANDOM-XCOR RANDOM-YCOR
    SET-INITIAL-TURTLE-VARS
    SET RATIONALITY RANDOM 5 + 5 ]
END

TO SET-INITIAL-TURTLE-VARS
  SET AGE 0
  FACE ONE-OF NEIGHBORS4
  SET MAX-AGE 100
  SET METABOLISM 1 + RANDOM 7
  SET WEALTH METABOLISM
  SET VISION 1 + RANDOM 7
END

TO GO
  ASK SUSTAINABLES
    [ TURN-TOWARD-RESOURCE ]
```

```
  EXTRACT
  ASK SUSTAINABLES
    [ MOVE-SUSTAINABLES ]
  ASK RATIONALS
    [ MOVE-RATIONALS ]
  ASK PATCHES [ GROW-RESOURCE ]
  ;;ASK TURTLES [ SET AGE (AGE + 1) ]
  IF TICKS MOD RESOURCE-GROWTH-INTERVAL = 0
    [ASK PATCHES [GROW-RESOURCE]]
  TICK
END

TO TURN-TOWARD-RESOURCE
  SET HEADING 0
  LET BEST-DIRECTION 0
  LET BEST-AMOUNT RESOURCE-AHEAD
  SET HEADING 90
  IF ( RESOURCE-AHEAD > BEST-AMOUNT )
    [ SET BEST-DIRECTION 90
    SET BEST-AMOUNT RESOURCE-AHEAD ]
    SET HEADING 180
  IF ( RESOURCE-AHEAD > BEST-AMOUNT )
    [ SET BEST-DIRECTION 180
    SET BEST-AMOUNT RESOURCE-AHEAD ]
    SET HEADING 270
  IF ( RESOURCE-AHEAD > BEST-AMOUNT )
    [ SET BEST-DIRECTION 270
    SET BEST-AMOUNT RESOURCE-AHEAD ]
    SET HEADING BEST-DIRECTION
END

TO-REPORT RESOURCE-AHEAD
  LET TOTAL 0
  LET HOW-FAR 1
  REPEAT VISION
  [ SET TOTAL TOTAL + [ RESOURCE-HERE ] OF PATCH-AHEAD HOW-FAR
    SET HOW-FAR HOW-FAR + 1 ]
  REPORT TOTAL
END

TO GROW-RESOURCE
  IF ( RESOURCE-HERE < MAX-RESOURCE-HERE )
```

```
  [ SET RESOURCE-HERE RESOURCE-HERE + NUM-RESOURCE-GROWN
  IF ( RESOURCE-HERE > MAX-RESOURCE-HERE )
  [ SET RESOURCE-HERE MAX-RESOURCE-HERE ]
  RECOLOR-PATCH ]
END

TO EXTRACT
  ASK RATIONALS [
  IFELSE RESOURCE-HERE > 0 AND RESOURCE-HERE >= RATIONALITY
  [ SET WEALTH FLOOR ( WEALTH + RATIONALITY ) ]
  [ SET WEALTH FLOOR ( WEALTH + RESOURCE-HERE / (COUNT TURTLES-HERE )) ]
  RECOLOR-PATCH]
  ASK RATIONALS [
  IFELSE RESOURCE-HERE > 0 AND RESOURCE-HERE >= RATIONALITY
  [ SET RESOURCE-HERE FLOOR ( RESOURCE-HERE - RATIONALITY )]
  [ SET RESOURCE-HERE 0 ]
  RECOLOR-PATCH]
  ASK SUSTAINABLES [
  IFELSE RESOURCE-HERE > 0 AND RESOURCE-HERE >= RATIONALITY
  [ SET WEALTH FLOOR ( WEALTH + RATIONALITY)];; - RATIONALITY * ( VALUE / 100 ))) ]
  [ SET WEALTH FLOOR ( WEALTH + RESOURCE-HERE / (COUNT TURTLES-HERE)) ]
  RECOLOR-PATCH]
  ASK SUSTAINABLES [
  IFELSE RESOURCE-HERE > 0 AND RESOURCE-HERE >= RATIONALITY
  [ SET RESOURCE-HERE FLOOR ( RESOURCE-HERE - RATIONALITY )];;- RATIONALITY * (VALUE / 100 )))]
  [ SET RESOURCE-HERE 0 ]
  RECOLOR-PATCH]
  ASK TURTLES [
    IFELSE SHOW-WEALTH?
    [ SET LABEL WEALTH ]
    [ SET LABEL "" ]]
END

TO MOVE-SUSTAINABLES
    IF (CEILING RANDOM-FLOAT 100.0) <= SUSTAINABLES-MOVE [FD 1 ]
   IF SUSTAINABLES-MOVE = TRUE [SET WEALTH ( WEALTH - METABOLISM )]
END
```

```
TO MOVE-RATIONALS
   IF (CEILING RANDOM-FLOAT 100.0) <= RATIONALS-MOVE [FD 1 ]
   IF RATIONALS-MOVE = TRUE [SET WEALTH ( WEALTH - METABOLISM )]
END
```

D – The NetLogo Code for the Greed Model

```
GLOBALS [ RESOURCE MAX-RESOURCE MIN-RESOURCE INITIAL-WEALTH ]

BREED [ SUSTAINABLES SUSTAINABLE ]
BREED [ RATIONALS RATIONAL ]
TURTLES-OWN [ METABOLISM VISION RATIONALITY WEALTH ]
PATCHES-OWN [ RESOURCE-HERE MAX-RESOURCE-HERE ]


TO SETUP
  CA
  SET MAX-RESOURCE 50
  SETUP-PATCHES
  SETUP-TURTLES
  RESET-TICKS
END

TO SETUP-PATCHES
   ASK PATCHES
  [ SET MAX-RESOURCE-HERE 0
    IF ( RANDOM-FLOAT 100.0 ) <= PERCENT-BEST-LAND
    [ SET MAX-RESOURCE-HERE MAX-RESOURCE
      SET RESOURCE-HERE MAX-RESOURCE-HERE ]]

  REPEAT 5
  [ ASK PATCHES WITH [ MAX-RESOURCE-HERE != 0 ]
    [ SET RESOURCE-HERE MAX-RESOURCE-HERE ]
    DIFFUSE RESOURCE-HERE 0.25 ]

  REPEAT 10
  [ DIFFUSE RESOURCE-HERE 0.25 ]
  ASK PATCHES
  [ SET RESOURCE-HERE FLOOR RESOURCE-HERE
    SET MAX-RESOURCE-HERE RESOURCE-HERE
    RECOLOR-PATCH ]
```

```
END

TO RECOLOR-PATCH
  SET PCOLOR SCALE-COLOR GREEN RESOURCE-HERE 0 MAX-RESOURCE
END

TO SETUP-TURTLES
  CREATE-SUSTAINABLES INITIAL-SUSTAINABLES
  [
    MOVE-TO ONE-OF PATCHES
    SET COLOR 65
    SET SHAPE "PERSON"
    SET-INITIAL-TURTLE-VARS
    SET RATIONALITY RANDOM 1 + 5 ]
  CREATE-RATIONALS INITIAL-RATIONALS
  [
    MOVE-TO ONE-OF PATCHES
    SET COLOR RED
    SET SHAPE "PERSON"
    SET-INITIAL-TURTLE-VARS
    SET RATIONALITY RANDOM 5 + 5 ]
END

TO SET-INITIAL-TURTLE-VARS
  FACE ONE-OF NEIGHBORS4
  SET METABOLISM 1 + RANDOM 7
  SET WEALTH METABOLISM
  SET VISION 1 + RANDOM 7
END

TO GO
  ASK SUSTAINABLES
    [ TURN-TOWARD-RESOURCE-T ]
  ASK RATIONALS
    [ TURN-TOWARD-RESOURCE-R ]
  EXTRACT
  ASK SUSTAINABLES
    [ MOVE-SUSTAINABLES ]
  ASK RATIONALS
    [ MOVE-RATIONALS ]
  ASK PATCHES [ GROW-RESOURCE ]
  IF TICKS MOD RESOURCE-GROWTH-INTERVAL = 0
```

```
    [ASK PATCHES [GROW-RESOURCE]]
  TICK
END

TO TURN-TOWARD-RESOURCE-R
  SET HEADING 0
  LET BEST-DIRECTION 0
  LET BEST-AMOUNT GREED
  SET HEADING 90
  IF ( RESOURCE-AHEAD-R > BEST-AMOUNT )
    [ SET BEST-DIRECTION 90
    SET BEST-AMOUNT RESOURCE-AHEAD-R ]
    SET HEADING 180
  IF ( RESOURCE-AHEAD-R > BEST-AMOUNT )
    [ SET BEST-DIRECTION 180
    SET BEST-AMOUNT RESOURCE-AHEAD-R ]
    SET HEADING 270
  IF ( RESOURCE-AHEAD-R > BEST-AMOUNT )
    [ SET BEST-DIRECTION 270
    SET BEST-AMOUNT RESOURCE-AHEAD-R ]
    SET HEADING BEST-DIRECTION
END

TO-REPORT RESOURCE-AHEAD-R
  LET TOTAL 0
  LET HOW-FAR 1
   REPEAT VISION
  [ SET TOTAL TOTAL + [ RESOURCE-HERE ] OF PATCH-AHEAD HOW-FAR
    SET HOW-FAR HOW-FAR + 1 ]
  REPORT TOTAL

END

TO TURN-TOWARD-RESOURCE-T
  SET HEADING 0
  LET BEST-DIRECTION 0
  LET BEST-AMOUNT RESOURCE-HERE
  SET HEADING 90
  IF ( RESOURCE-HERE > BEST-AMOUNT )
    [ SET BEST-DIRECTION 90
    SET BEST-AMOUNT RESOURCE-AHEAD-T ]
    SET HEADING 180
```

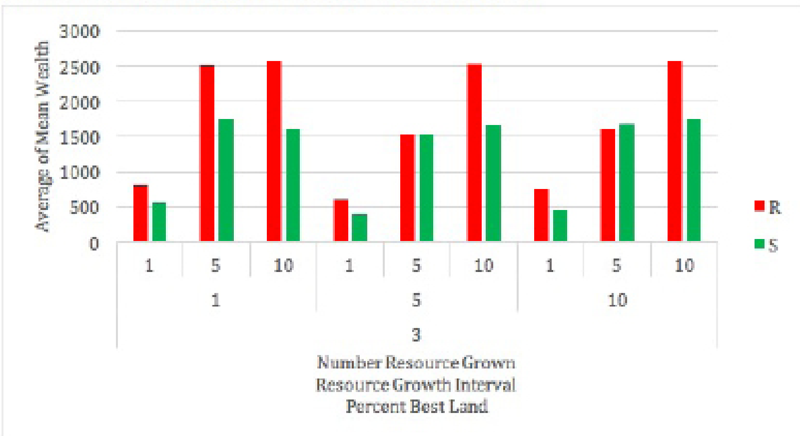
```
  IF ( RESOURCE-AHEAD-T > BEST-AMOUNT )
    [ SET BEST-DIRECTION 180
    SET BEST-AMOUNT RESOURCE-AHEAD-T ]
    SET HEADING 270
  IF ( RESOURCE-AHEAD-T > BEST-AMOUNT )
    [ SET BEST-DIRECTION 270
    SET BEST-AMOUNT RESOURCE-AHEAD-T ]
    SET HEADING BEST-DIRECTION
END

TO-REPORT RESOURCE-AHEAD-T
  LET TOTAL 0
  LET HOW-FAR 1
   REPEAT VISION
  [ SET TOTAL TOTAL + [ RESOURCE-HERE ] OF PATCH-AHEAD HOW-FAR
    SET HOW-FAR HOW-FAR + 1 ]
  REPORT TOTAL

END

TO GROW-RESOURCE
  IF ( RESOURCE-HERE < MAX-RESOURCE-HERE )
  [ SET RESOURCE-HERE RESOURCE-HERE + NUM-RESOURCE-GROWN
  IF ( RESOURCE-HERE > MAX-RESOURCE-HERE )
  [ SET RESOURCE-HERE MAX-RESOURCE-HERE ]
  RECOLOR-PATCH ]
END

TO EXTRACT
  ASK RATIONALS [
  IFELSE RESOURCE-HERE > 0 AND RESOURCE-HERE >= RATIONALITY
  [ SET WEALTH FLOOR ( WEALTH + RATIONALITY ) ]
   [ SET WEALTH FLOOR ( WEALTH + RESOURCE-HERE / (COUNT TURTLES-
HERE )) ]
  RECOLOR-PATCH]
  ASK RATIONALS [
  IFELSE RESOURCE-HERE > 0 AND RESOURCE-HERE >= RATIONALITY
  [ SET RESOURCE-HERE FLOOR ( RESOURCE-HERE - RATIONALITY )]
  [ SET RESOURCE-HERE 0 ]
  RECOLOR-PATCH]
  ASK SUSTAINABLES [
  IFELSE RESOURCE-HERE > 0 AND RESOURCE-HERE >= RATIONALITY
```

```
    [ SET WEALTH FLOOR ( WEALTH + RATIONALITY)];; - RATIONALITY * (
VALUE / 100 ))) ]
    [ SET WEALTH FLOOR ( WEALTH + RESOURCE-HERE / (COUNT TURTLES-
HERE)) ]
    RECOLOR-PATCH]
    ASK SUSTAINABLES [
    IFELSE RESOURCE-HERE > 0 AND RESOURCE-HERE >= RATIONALITY
     [ SET RESOURCE-HERE FLOOR ( RESOURCE-HERE -  RATIONALITY )];;-
RATIONALITY * (VALUE / 100 )))]
    [ SET RESOURCE-HERE 0 ]
    RECOLOR-PATCH]
    ASK TURTLES [
     IFELSE SHOW-WEALTH?
     [ SET LABEL WEALTH ]
     [ SET LABEL "" ]]
  END

  TO MOVE-SUSTAINABLES
     IF (CEILING RANDOM-FLOAT 100.0) <= SUSTAINABLES-MOVE [FD 1 ]
     IF SUSTAINABLES-MOVE = TRUE [SET WEALTH ( WEALTH - METABOLISM )]
  END

  TO MOVE-RATIONALS
     IF (CEILING RANDOM-FLOAT 100.0) <= RATIONALS-MOVE [FD 1]
     IF RATIONALS-MOVE = TRUE [SET WEALTH ( WEALTH - METABOLISM )]
  END
```

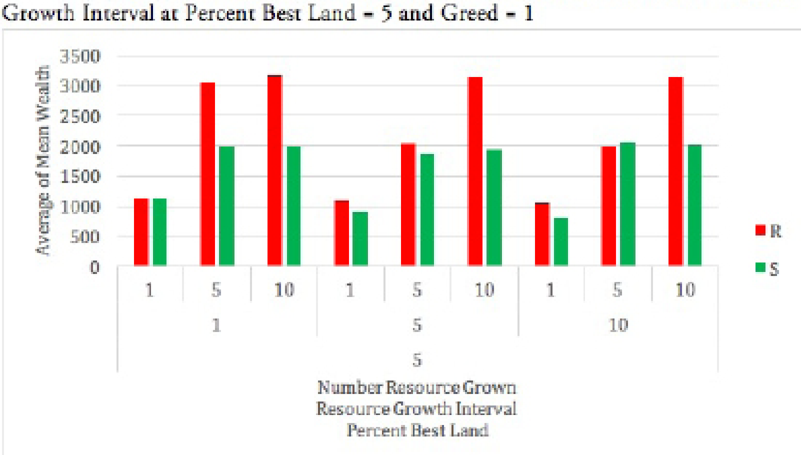
Appendix II — Graphs

A – Greed Level = 1

Graph 1a. Wealth of Rationals vs Sustainables: Number Resource Grown and Resource Growth Interval at Percent Best Land = 3 and Greed = 1



Graph 1b. Wealth of Rationals vs Sustainables: Number Resource Grown and Resource Growth Interval at Percent Best Land = 5 and Greed = 1



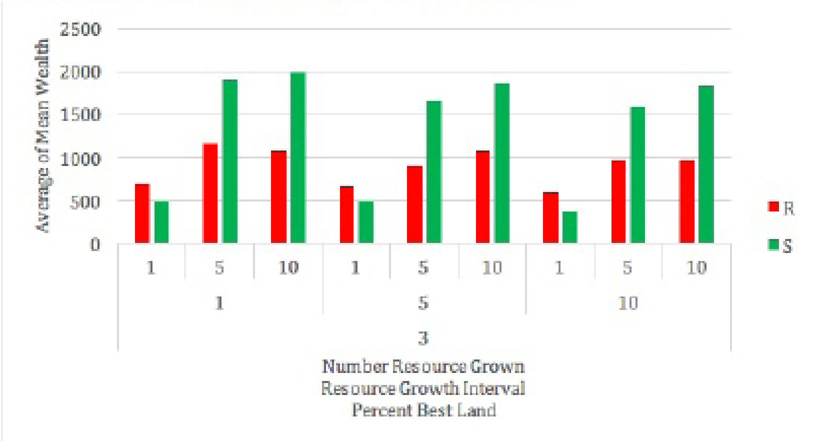
B – Greed Level = 50

Graph 2a. Wealth of Rationals vs Sustainables: Number Resource Grown and Resource Growth Interval at Percent Best Land = 3 and Greed = 50

Graph 2b. Wealth of Rationals vs Sustainables - Number Resource Grown and Resource Growth Interval at Percent Best Land = 5 and Greed = 50

C – Greed Level = 100

Graph 3a. Wealth of Rationals vs Sustainables: Number Resource Grown and Resource Growth Interval at Percent Best Land = 3 and Greed = 100



Graph 3b. Wealth of Rationals vs Sustainables: Number Resource Grown and Resource Growth Interval at Percent Best Land = 5 and Greed = 100