Agent-Based Modelling Assessment 1

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1 Aim

This report aims to investigate the impact of various factors on the wealth distribution and the survival rate of turtles in the sugarscape model. In this report, the following 2 models from the NetLogo Models Library are investigated and compared.

- Sugarscape 2 Constant Growback model (Li and Wilensky, 2009a)
- Sugarscape 3 Wealth Distribution model (Li and Wilensky, 2009b)

The differences between the 2 models is that the Sugarscape 3 model introduces reproduction and replacement, where turtles who have reached a certain age will die, and dead turtles are replaced by a new turtle placed in a random position. The Sugarscape 2 model can be interpreted as a representation of one generation of turtles, where the Sugarscape 3 model simulates multiple generations.

1.1 Research Question

How will the survival rate and the Gini Index change according to population growth? Is there a difference in the survival rate and the Gini Index when considering reproduction?

1.2 Hypothesis

The increase in population is expected to lower the survival rate and increase the Gini Index due to intesifying competition. The wealth distribution among turtles are expected to even out when considering reproduction. Turtles being 'stuck' to different areas with different amount of sugar may be the cause of inequality, and the reproduction process introduces more fluidness to the system.

2 Methods

We modified the Sugarscape Models in the NetLogo Models Library to change constants on the interface and the BehaviourSpace tool on NetLogo (Epstein and Axtell, 1996) to report the performance of each model. Further investigation on the wealth distribution was conducted to identify the mechanism behind the observed phenomenon.

2.1 Changing Variables and Iterations

Using the BehaviorSpace tool, we have simulated the performance using variables shown in Table 1 for both Sugarscape 2 and 3 models. All variations of the model were repeated 20 times. All other variables were unchanged from the original state.

Table 1: The variables and the range considered in this report

Variable	Explanation	Experimented Values
`initial_population`	Initial population of turtles.	200, 400, 600, 800, 1000
`max-metabolism`	Maximum metabolism of turtles. Metabolism for each turtle is assigned randomly between 1 and this variable.	2, 4, 6, 8, 10
`max-vision`	Maximum vision of turtles. Vision for each turtle is assigned randomly between 1 and this variable.	2, 4, 6, 8, 10

2.2 Reporters of Performance

We have observed the reporters in Table 2 to measure the performance.

Table 2: Observatory statistics reported by the models

Reporter	Explanation
Survival Rate of Turtles	Defined as the percentage of turtles alive at the natural state (Sugarscape 2), or the percentage of turtles who survived from starvation until their death by age (Sugarscape 3)
Gini Index	Cumulative proportion of wealth compared to the population, defined as the ratio of area under the Lorenz curve compared to perfect equality, as implemented in Li and Wilensky (2009b)
Population at natural age	Population of turtles at the natural state. The survival rate is the ratio of this value divided by the initial population.

Considering the warm-up period, observations were made at the natural state defined in Table 3.

Table 3: Definitions of natural state for each model

Model	Definition of natural state
Sugarscape 2	100 ticks after the last death of turtle
Sugarscape 3	Observation window of 2 to 5 maximum lifespan lengths (100 ticks) after start,for survival rates, or 5 maximum lifespan lengths for other measurements

2.3 Comparison Between Models

The comparison between models are done on the basis of population at the natural state. The Sugarscape 2 model has less turtles than the initial state, while the Sugarscape 3 model has constant population.

3 Results

3.1 Survival Rate

The observed survival rates are shown in Figure 1.

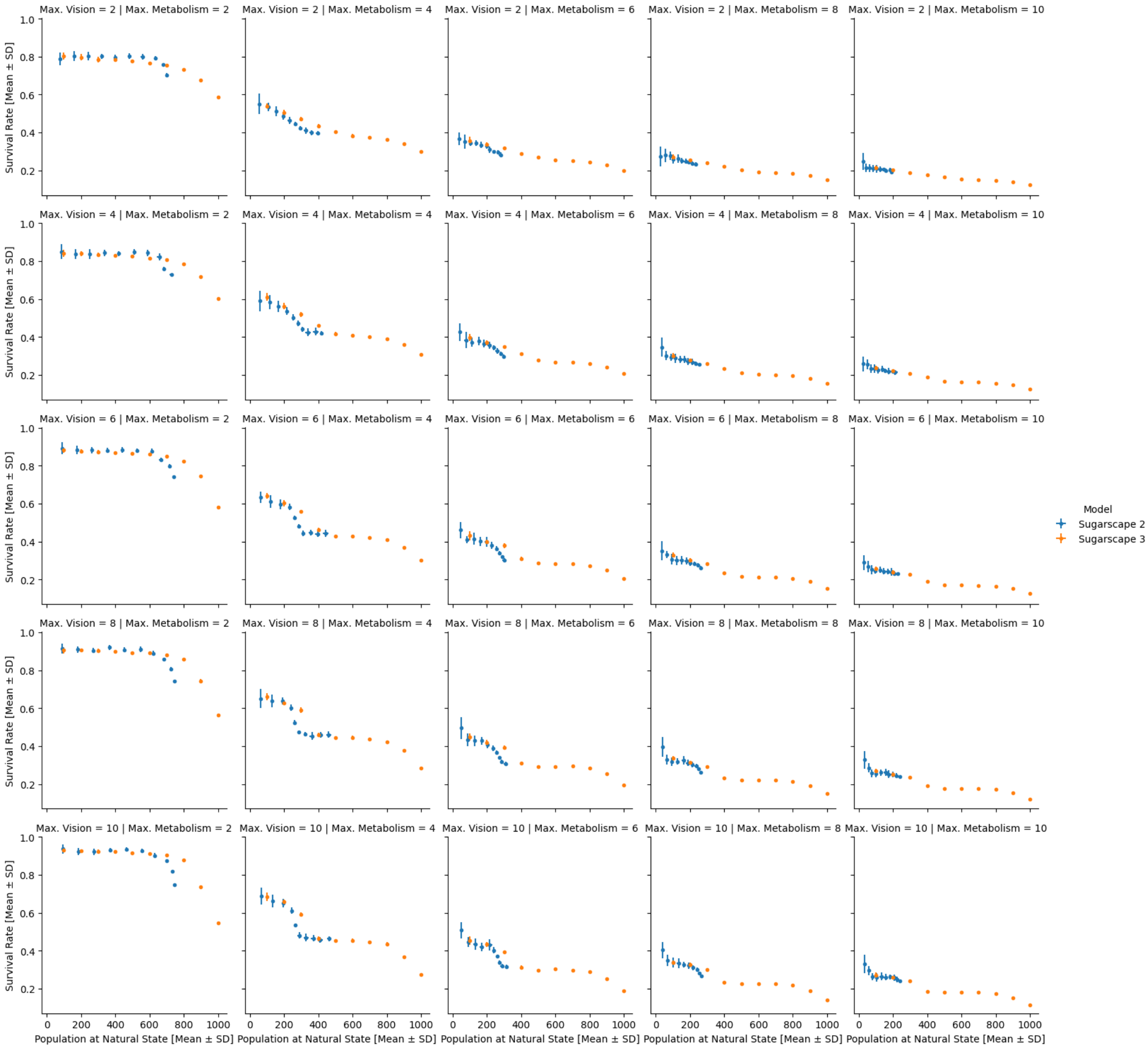

Figure 1: Comparison of survival rates of the models. Higher survival rates are achieved by lower maximum metabolism, higher maximum vision, and lower population. A similar value is observed between the two models. A larger variance was observed for the Sugarscape 2 model, and in conditions with smaller population.

A significant drop of survival rate is observed for maximum metabolism of 6 and above. Since the maximum amount of sugar supplied by a patch in Sugarscape is 4, all turtles with metabolism over 4 die before the natural state.

3.2 Gini Index

The Gini Index for each simulation is shown in Figure 2:

The Sugarscape 3 model results in a higher Gini Index in general and is less affected by the population of turtles. A distinctive N-shaped pattern in accordance with population change,

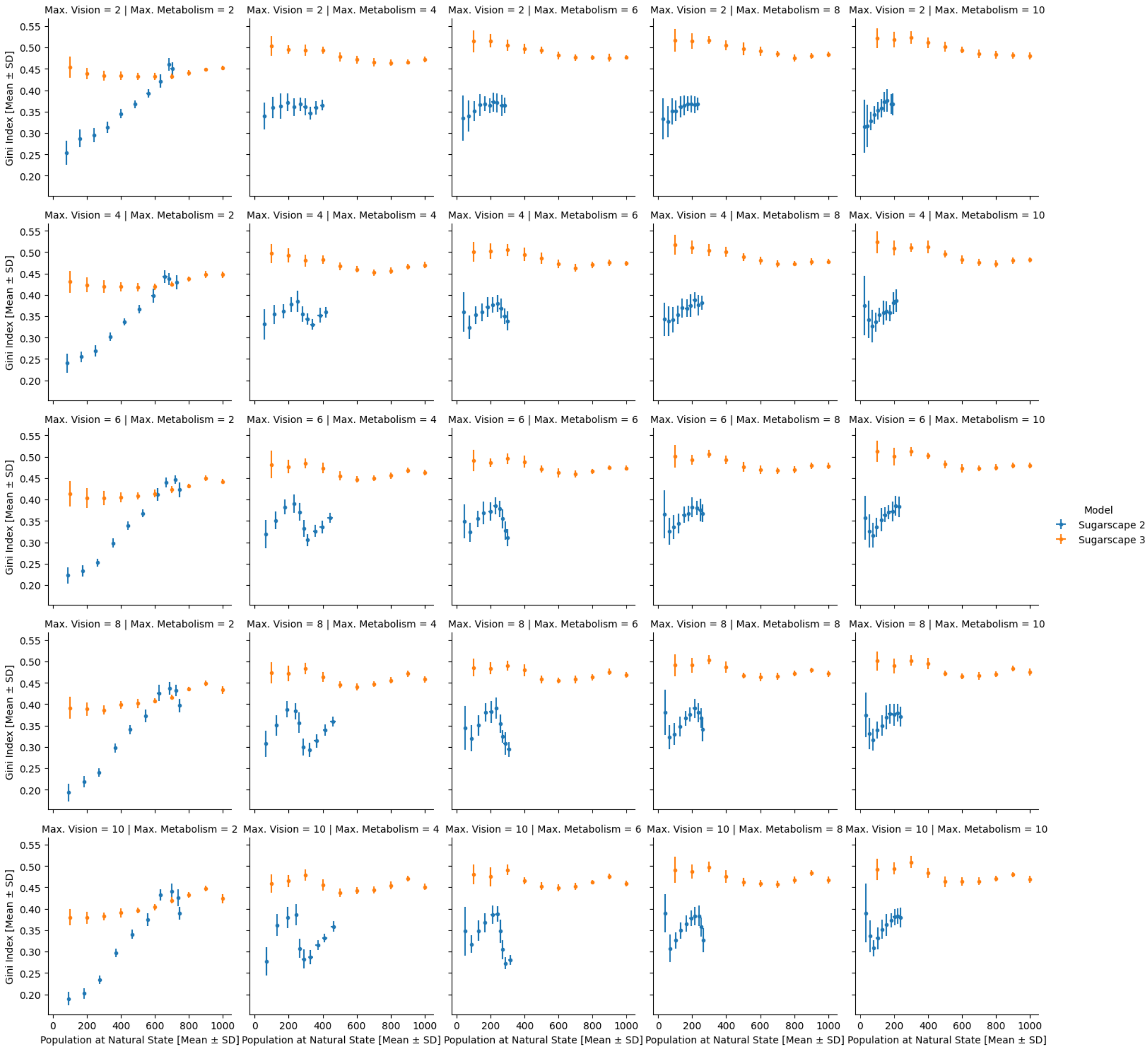

Figure 2: Comparison of the Gini Index of the models. Higher maximum metabolism and higher maximum vision results in a high Gini Index. Overall, the Sugarscape 3 model tends to have a higher Gini Index compared to the Sugarscape 2 model. The variance is higher when there is a smaller population.

most apparent in conditions with high vision and moderate metabolism range, as shown in Figure 3.

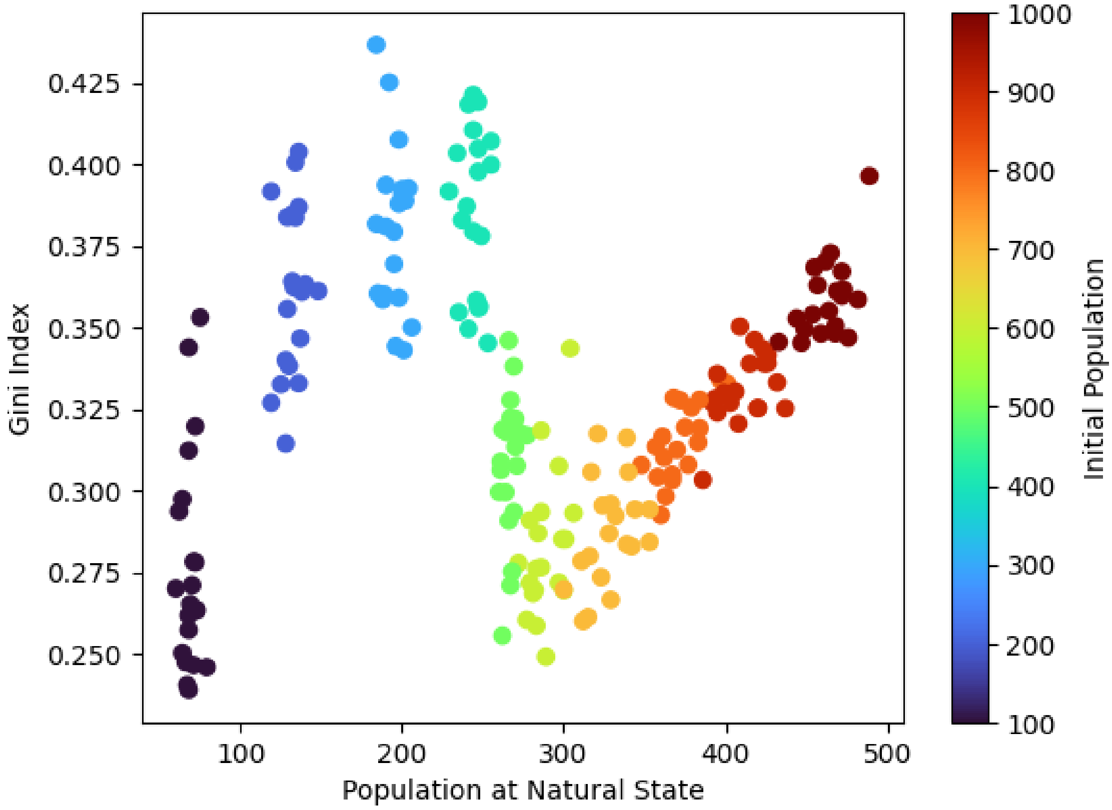

Figure 3: Gini Index for Sugascape 2 model with `max-vision` = 10 and `max-metabolism` = 4.

4 Discussion

4.1 Gini Index

4.1.1 Relationship with Population

An N-shaped pattern was observed for the relationship between the population and the Gini Index, as illustrated in Figure 3. To identify the reason behind this phenomenon, we analysed the behaviour of wealth distribution of a typical generated by each variant. Snapshots and the wealth distribution at the natural state for different initial populations are shown in Figure 4. The net wealth gained per tick is the amount of sugar for each turtle divided by the ticks passed, corresponding to the average difference between the collected sugar and metabolism per tick.

Distinct groups in the wealth distribution can be observed for all 4 simulations. The discrete distribution of metabolism and the steady sugar availability for each turtle may be causing this situation.

The model with initial population of 100 has most of the turtles clustered in the highly-supplying areas, allowing a larger income of sugar. This is confirmed by having the largest maximum net wealth gained per tick among the models.

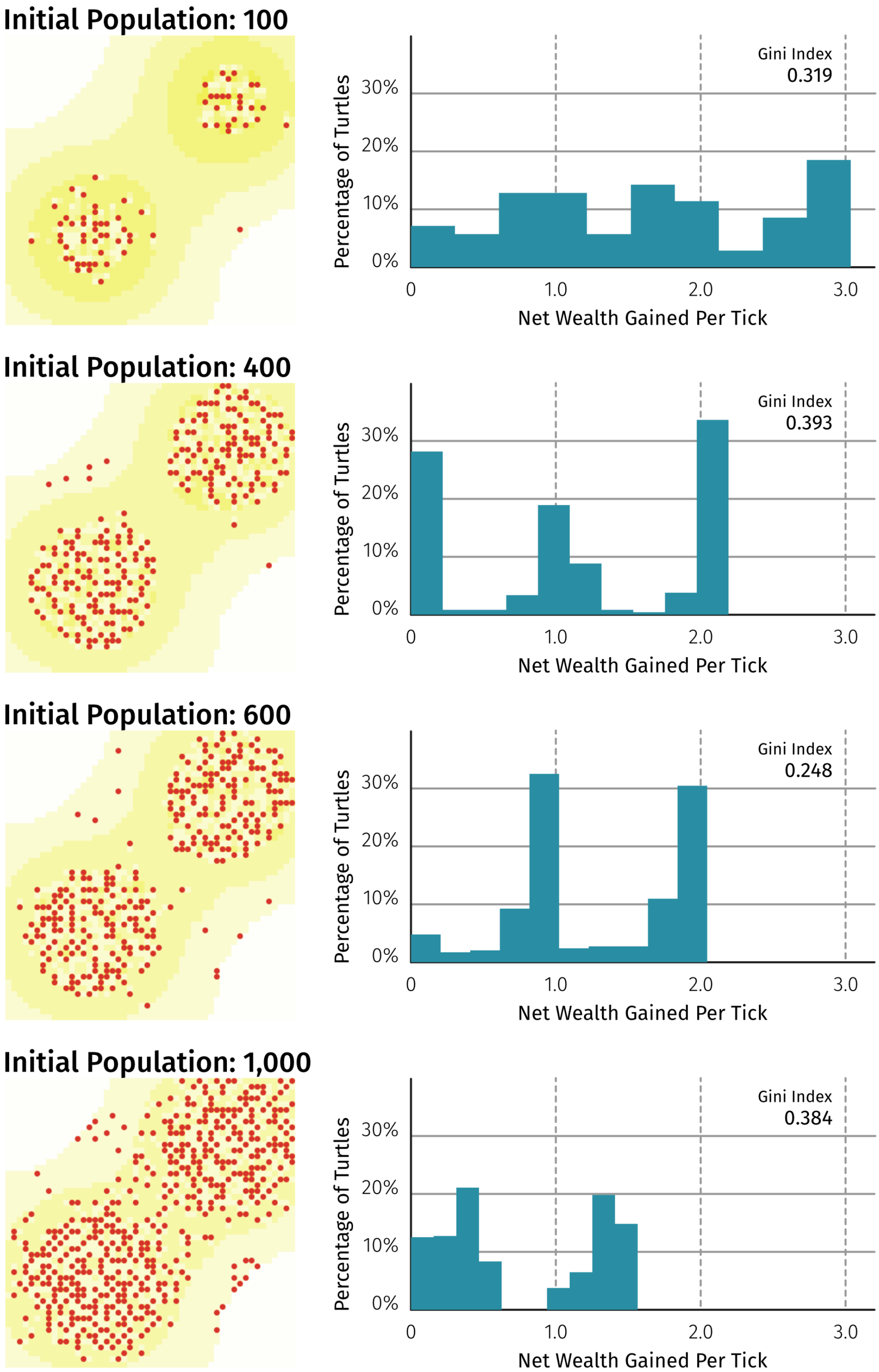

Figure 4: Snapshot of natural state (left) and the histogram of wealth distribution (right) for models with different initial population (`max-vision` = 10 and `max-metabolism` = 4). The range was divided into 10 bins to create the histogram, and was plotted according to the net wealth gained per tick.

The second model has 3 distinct groups, each clustered around 0, 1 and 2. This can be explained as turtles are having a steady income of 1, 2 or 3, but no longer having access to a steady income of 4 seen in the first model.

The third model shows a similar pattern, with a slightly lower net wealth gained per tick value for the whole population and a significantly smaller population of the group clustered around 0. Each turtle had a slightly smaller income, and this had a fatal impact on the 'poorest' group, reducing population. The improvement in the Gini Index was a result of this starvation, not a result of equal distribution of sugar.

The final model sees a decrease of the net wealth of groups in general, and the groups spreading out. The competition has made it difficult to gain a steady (integer) amount of income, leading to a decline in the income. The Gini Index has increased because the same absolute difference now has a different ratio, making the poorer group having less share of the total wealth.

In conclusion, the segregation into distinct groups and starvation of poorest groups may be causing the varying Gini Index and the survival rate resulting in the 'N-shaped' pattern observed in the scatter plot.

4.1.2 Considering Reproduction

The introduction of reproduction in the Sugarscape 3 model has caused the Gini Index to increase, indicating higher inequality (Figure 2). This result contradicts our hypothesis, where we have predicted the 'resetting' evens out the distribution of wealth.

The wealth distribution for the Sugarscape 3 model is negatively skewed, as shown in Figure 5. The constant supply of turtles in unsurvivable areas with low sugar supply contributes to keeping a steady amount of poor population, while this group cannot survive until the natural state in the Sugarscape 2 model. The existence of the poor group is the cause of a higher Gini Index.

4.2 Survival Rate

The 2 models have a similar survival rate when the final population is similar, suggesting a similar situation of competition regardless of their differences. As population increases, there is an initial steep drop, followed by a relatively flat segment where the survival rate is steady.

This can also be explained through the observations of Figure 4. The initial drop is explained by the difference between the second and third model, where the 'poorest' group can no longer survive. The relatively flat area that follows is illustrated between the third and the fourth model, where the average income decreases but no significant population groups starve.

The 'N-shape' of this graph is constructed through two patterns:

1. survival rate does not change significantly while the Gini Index increases
2. the survival rate and the Gini Index both drop

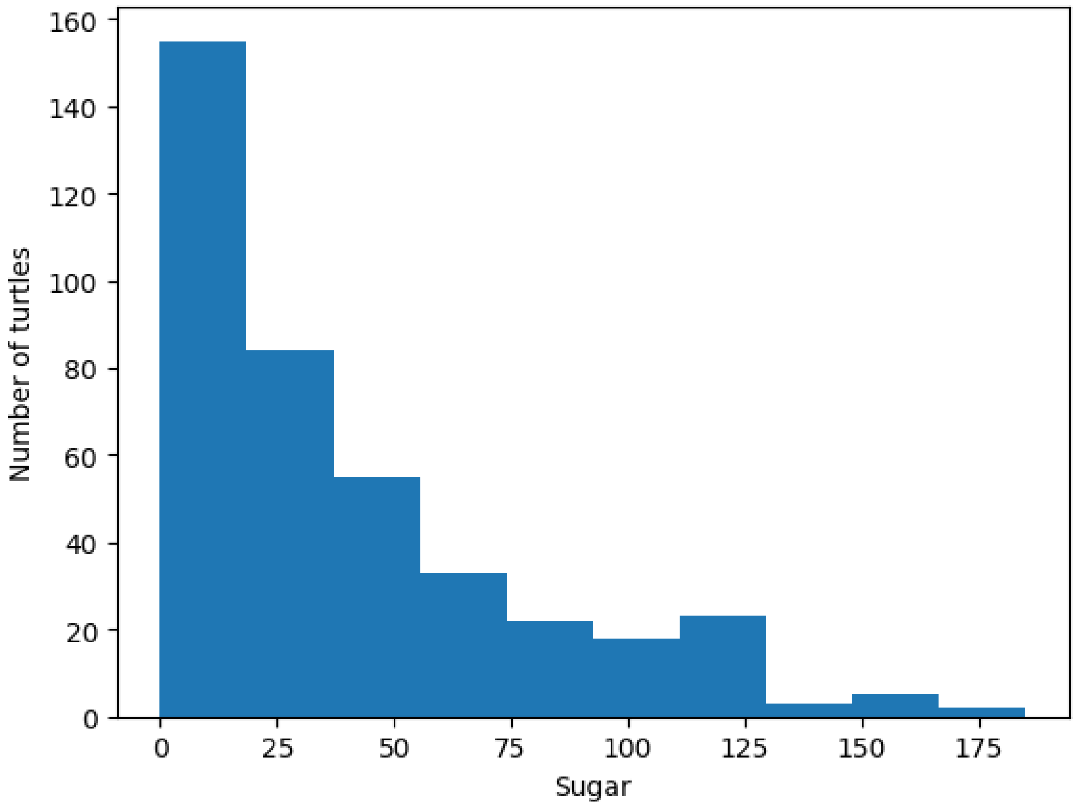

Figure 5: Distribution of wealth in a Sugarscape 3 model at the natural state. `max-vision` = 6, `max-metabolism` = 4

The former may be caused by the 'left-shift' of the wealth distribution histogram observed between the third and fourth model in Figure 4, while the latter may be caused by the poorest group forced into starvation.

5 Conclusion

We have observed the impact of population and characteristics of turtles on the Gini Index and the survival rate of the Sugarscape models. These are both essential parameters when measuring the equality of wealth distribution. Our analysis has revealed that an improvement in the Gini Index may be a result of poor groups starving, thus excluded from calculation. Further development of the Sugarscape 3 model for different reproduction rules provides room for potential future research. By placing newborn turtles in locations in relationship to the parent, instead of a random distribution, may enable us to reflect the real-world parameters of parental influence and inheritance.

Word count: 1,499 words.

The code for this report is available on GitHub.

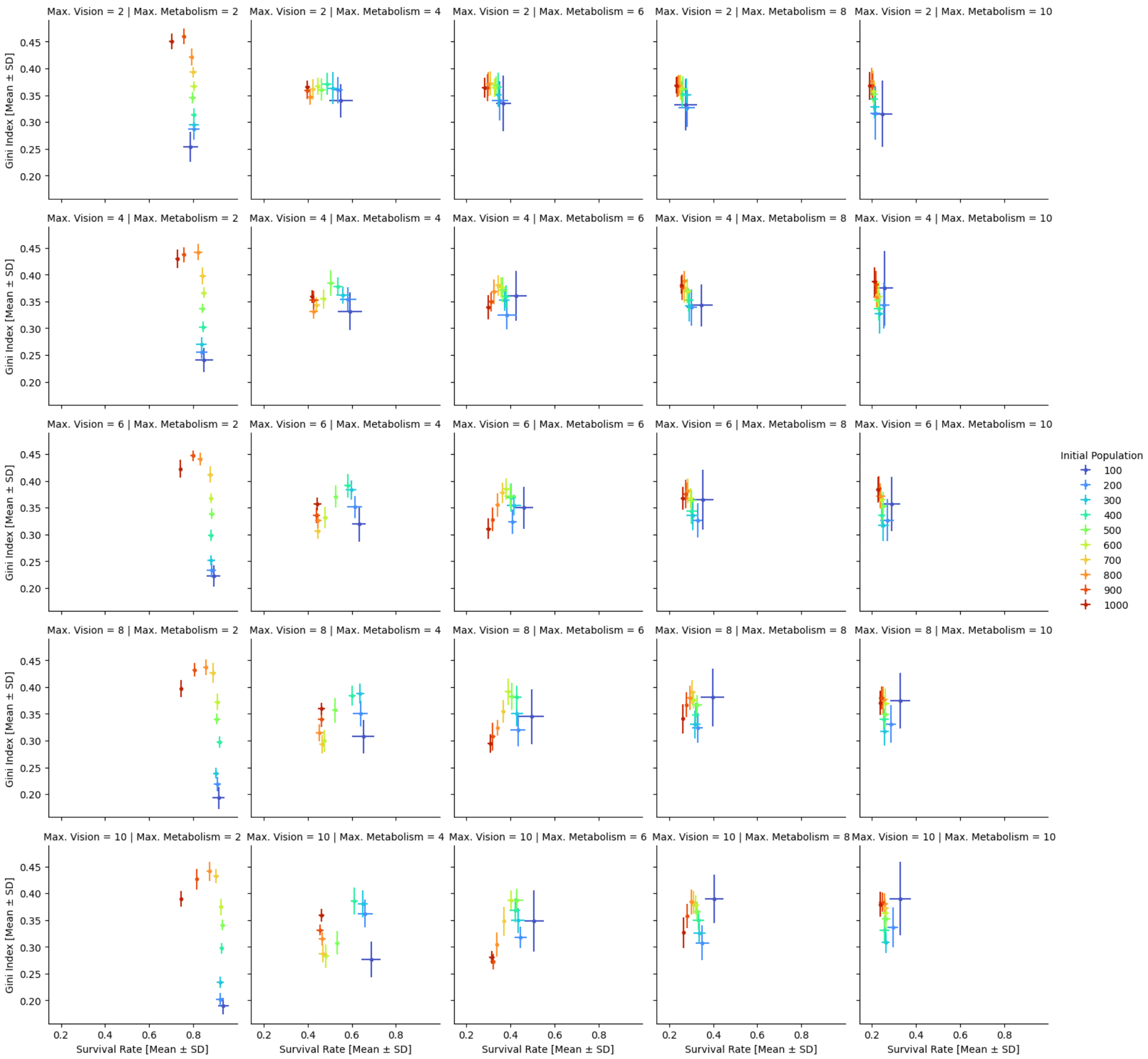

Figure 6: The relationship between the survival rate of turtles and the Gini Index for the Sugarscape 2 model.

Appendix

The reporters added to the model are the Gini Index and the survival rate.

Gini Index

The Gini Index shows the distribution of wealth among the population, where 0 shows complete inequality and 1 showing complete equality.

The implementation was done by the following function, inherited from the Sugarscape 3 model (Li and Wilensky, 2009b) with minor changes.

```
to update-lorenz-and-gini ; turtle context
  let num-people count turtles
  let sorted-wealths sort [sugar] of turtles
  let total-wealth sum sorted-wealths
  let wealth-sum-so-far 0
  let index 0
  set gini-index-reserve 0
  set lorenz-points []
  repeat num-people [
    set wealth-sum-so-far (
      wealth-sum-so-far + item index sorted-wealths
    )
    set lorenz-points (
      lput ((wealth-sum-so-far / total-wealth) * 100) lorenz-points
    )
    set index (index + 1)
    set gini-index-reserve
      gini-index-reserve +
      (index / num-people) -
      (wealth-sum-so-far / total-wealth)
  ]
  set gini-index ((gini-index-reserve / count turtles) * 2)
end
```

Survival Rate

The survival rate is the ratio of turtles who have not starved to death. In the Sugarscape 2 model this is the percentage of initial turtles surviving at the natural state, and is reported by the following line of code in the `go` procedure.

```
  ; Sugarscape 2 model
  set survival-rate ((count turtles) / initial-population)
```

For the Sugarscape 3 model where turtles die when reaching the maximum age, the survival rate is the ratio of turtles who have reached their maximum age without starving. In order to omit the warm-up period, the observation was made for the turtles who died between 2 and 5 maximum age lengths (100 ticks) after the start of the model.

This is achieved by setting 2 global variables to count the total deaths and those who died of starvation, and executing the following code within the `go` procedure.

```
; Sugarscape 3 model
ask turtles [
  ;; check if cause of death is natural or of starvation
  if sugar ≤ 0 or age > max-age [
    set dead-pop (dead-pop + 1)
    if sugar ≤ 0
    [ set starved-pop (starved-pop + 1) ]
    hatch 1 [ turtle-setup ]
    die
  ]
  run visualization
]

;; reset the starved ratio after 2 max ages have passed
if ticks ≤ (max-max-age * 2)
[
  set starved-pop 0
  set dead-pop 0
]

;; calculate starved ratio, if none dead yet rate is 1
carefully
[ set survival-rate ( 1 - ( starved-pop / dead-pop ) ) ]
[ set survival-rate 1 ]
```

References

Epstein, J. M. and Axtell, R. L. (1996) Growing Artificial Societies: Social Science from the Bottom Up. The MIT Press. doi: 10.7551/mitpress/3374.001.0001.

Li, J. and Wilensky, U. (2009a) 'NetLogo Models Library: Sugarscape 2 Constant Growback'. Evanston, IL.: Center for Connected Learning and Computer-Based Modeling, Northwestern University.

Li, J. and Wilensky, U. (2009b) 'NetLogo Models Library: Sugarscape 3 Wealth Distribution'. Evanston, IL.: Center for Connected Learning and Computer-Based Modeling, Northwestern University.