A tale of two Sugarscapes:

A systematic model comparison

1 | Introduction and model outline

The focus of this work is on two variants of the Epstein and Axtell's Sugarscape model (Epstein and Axtell, 1996). The purpose is to develop a systematic means of understanding each model before proceeding to compare macro-level outcomes between models with different resource renewal rates, SS1 and SS2.

The key parameters of each model are outlined in Table 1. With population (*p)* set at the outset and s_{growth} the only differentiating factor between the models, the central research enquiry is around the impact of changing *p* within each model and any systemic differences observed as a result of s_{growth}.

1 | Table 1 | Sugarscape model 1 (SS1) and model 2 (SS2) parameters

Parameter	SS1 - (immediate grow back)	SS2 - (constant grow back)
Base sugar allocation per patch (s_{base})	Pre-determined allocation between 0-4 (based on input file – see appendix A.2)	
Sugar replenishment rate (s_{growth})	Replenish each patch based on s_{base}	+ 1 per 'tick' up to patch s_{base}
Starting population range (p_{start})	Selected for each scenario between 0-1500	
Population (p_{end})	Population at the end of scenario/at the end of warm-up period	
Metabolic rate (*m*)	Random between 1-4	
Vision (*v*)	Random between 1-6	
Initial sugar distribution (s_{start})	Random between 5-25	
Accumulated sugar level (s_{end})	Unique per agent in population	

Note: Inspired by (The Journal of Artificial Societies and Social Simulation, n.d.) – link in bibliography

Both SS1 and SS2 are survival and wealth accumulation models (Terna, 2001). Agents are randomly seeded with heterogenous parameters (Table 1) while moving around the world as per figures 1.1 & 1.2. The agent's purpose is to find an unoccupied sugar patch with highest sugar value within their field of vision (*v*) in order to satisfy the following constraint and ensure their survival: $S_{end} \geq 0$ where $S_{end} = S_{start} + S_{growth} - m$. If $S_{end} < 0$, the agent will 'die' and be removed from the simulation decreasing *p* and affecting *m*, *v* and s_{end}.

1| Figure 1 | Initial Sugarscape population seed

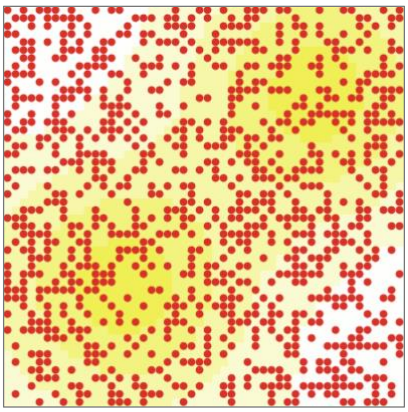
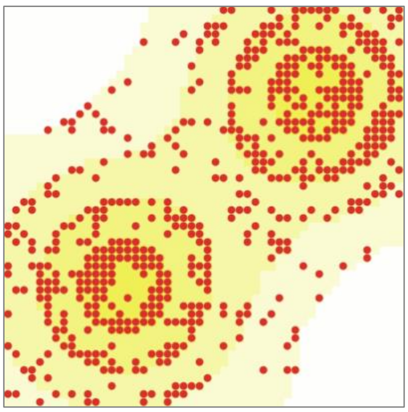


Fig. 1.1 |
p = 1000
m = 2.52
v = 3.47

1| Figure 2 | Indicative Sugarscape end state

Fig. 1.2 |
p = 595
m = 1.99
v = 3.65



Note: (i) A population of 1,000 randomly distributed across space. **(ii)** Agents are not allowed to occupy the same patch. **(iii)** Simulation ran until a steady state was reached that was designated an 'end state' for figure 1.2. **(iv)** Intensity of yellow denotes the concentration of sugar (s_{base}) ranging between 0 and 4.

2 | Systematic evaluation of the two worlds

Ad-hoc runs of the model and logical exploration of model dynamics suggest hypotheses that ought to be tested (Table 2). Most systemic variation is expected before an equilibrium state is reached affecting *p*,*m*&*v*.

Although *s* fluctuates as agents die, the final ‘settled point’ determines the rate of wealth accumulation in perpetuity. This results in a state where agents with traits to secure a higher yielding sugar patch early continue to prosper widening the wealth gap as the model does not allow for ‘social mobility’ to take place.

2 | Table 2 | Sugarscape hypotheses

Pre-equilibrium hypotheses (in scope):

Parameter	SS1	SS2
H1 - Warm-up period	With agents who cannot get sufficient sugar being eliminated, a warm-up period is expected after which the population will be constant. SS1 is expected to be shorter than SS2 due to ‘growback’ component in SS2.	
H2 - Population (p_{end})	End/stable population will be lower than initially seeded population	Given grow-back period, stable population is expected to be lower compared to SS1
H3 - Metabolic rate (*m*)	Expect lower vs start	Expect lower vs start and vs SS1
H4 - Vision (*v*)	Except to get higher vs start	Expect to get higher vs start and vs SS1

Post-equilibrium hypotheses (out of scope):

Parameter	SS1	SS2
H5 - Sugar level (s_{end})	Inequality to keep increasing Compare t_0 and $t_{equilibirum}$ Lorenzo curve and time series of GINI coefficients	Inequality to keep increasing but at slower rate compared to SS1 Compare t_0 and $t_{equilibirum}$ Lorenzo curve and time series of GINI coefficients

Note: due to limits of scope in this paper, H5 is left for further research and is considered out of scope for the body of this work

To evaluate the in-scope hypotheses experiments are ran with parameters in Table 3 with output data processed in python workflow.[1]

2 | Table 3 | Experiment parameters

Parameter	Values for SS1 and SS2	Rationale
Initial population	Between 100 and 1500 at 50 population intervals	More detailed (every 50 pop) to capture better tipping points, going beyond model range for upper range to more deeply explore model behaviour
Repetitions	30	Arbitrary decision
Time limit	100	In order to run same experiment for SS1 and SS2, longer timeframe chosen to accommodate expected longer warm-up period for SS2

Note: Reporter code in Appendix A1

[1] Python workflow along with input experiment data can be found on GitHub, here (http://bit.ly/abm_2_2020).

3 | Results

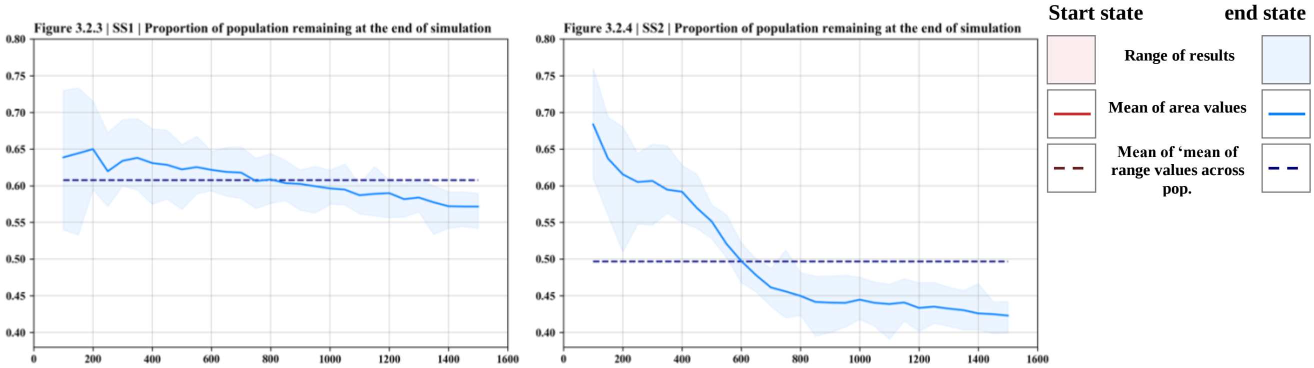
All results are presented for H1-H4 and discussed collectively below with reference to specific figures.

3 | Table 4 | H1 – warm-up period summary statistics

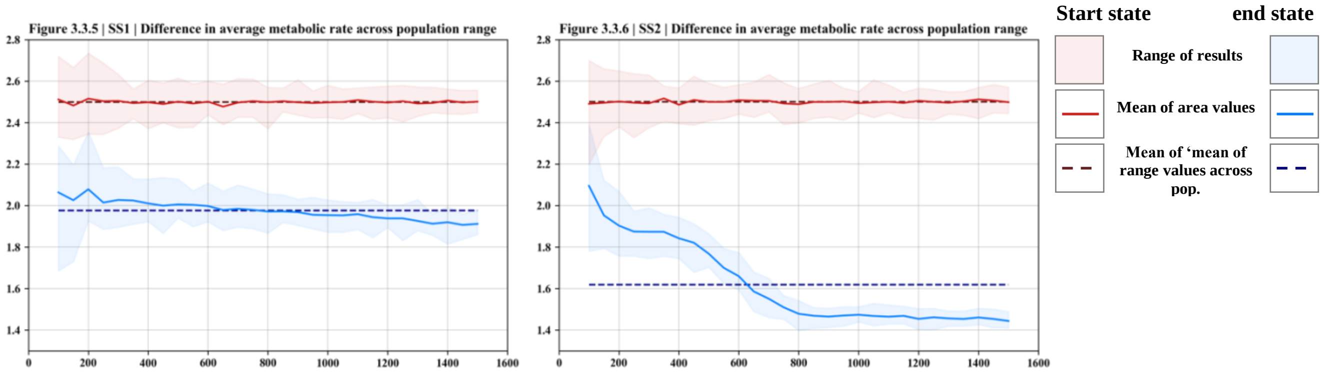
Parameter	SS1 - (immediate grow back) (1 d.p.)	SS2 - (constant grow back) (1 d.p.)
Count	870	
Mean	24.9	76.1
Standard deviation	0.3	20.0
Minimum	20.0	29.0
25%	25.0	59.0
50%	25.0	82.5
75%	25.0	94.0
Maximum	25.0	100.0

Note: Measured by identifying the tick at which the population stopped changing by taking minimum population count and finding the first row within the sorted data frame where the value is equal to this minimum. This is performed in a loop across all individual experiments for SS1 and SS2.

3.2 | H2 | population decrease



3.3 | H3 | metabolic rate



3.4 | H4 | vision range

Figure 3.4.7 | SS1 | Difference in average vision range across population range

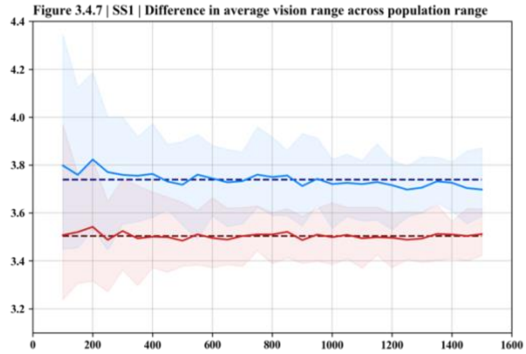
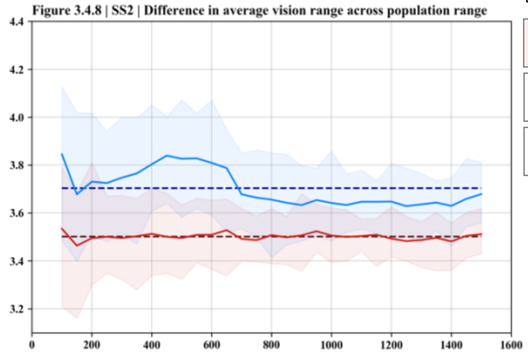
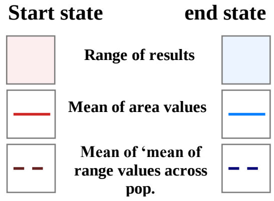


Figure 3.4.8 | SS2 | Difference in average vision range across population range





4 | Discussion and further research

Overall, the behaviour of both models follows similar patterns.

Population levels (*p*) decrease (H2) over the course of a warm-up period to reach a steady state after ~25 ticks for SS1 and ~76 ticks for SS2 (H1). Given the gradual grow-back of sugar in SS2 greater variability is observed as per the higher standard deviation rate noted as part of Table 3.4 (20 for SS2 vs 0.3 for SS1).

The population parameters are directionally similar, a lower metabolism (*m*) helps an individual survive and therefore only those with lower *m* remain at the end (H3). The reverse is observed with vision as a higher *v* increases the chance of survival (H4).

At a macro level, trends observed for SS1 are exaggerated for SS2, particularly from population 400 onwards. In H2, the mean *p* across the experiments is ~60% vs 50% for SS1 and SS2 respectively; *m* is ~2 vs. 1.6 and *v* is comparatively similar at ~3.7 for both models. However, across all parameters, SS2 exhibits a dual state which is 'tipped' at ~400 population and settles at ~800 population. Once (re-)settled *p* is at ~45%, *m* at ~1.5 while *v* counter intuitively decreases despite the advantage it would theoretically provide at a higher value.

Further research could tackle the SS2 tipping points highlighted above as well as examine measures of inequality such as GINI and the impact s_{growth} and p_{start} have on the rate at which inequality is likely to grow (H5). In addition, the rate of movement, or area covered by each agent could be of interest as although a steady state is achieved by way of total population, SS2 in particular does not remain static.

| *Word count: 593*

Bibliography

Epstein, J.M., Axtell, R., 1996. Growing artificial societies: social science from the bottom up. Brookings Institution Press.

Terna, P., 2001. Creating artificial worlds: A note on sugarscape and two comments. J. Artif. Soc. Soc. Simul. 4, 9.

The Journal of Artificial Societies and Social Simulation, n.d. Epstein and Axtell’s Sugarscape. Epstein Axtells Sugarscape. URL http://jasss.soc.surrey.ac.uk/12/1/6/appendixB/EpsteinAxtell1996.html (accessed 2.21.20).

Appendix

A.1 | Copy of reporters used

Reporter in NetLogo:
(1) Counting the population (p)
(2) Average metabolism (m) of entire population
(3) Average vision (v) of turtles
(4) Proportion of turtles remaining

```
count turtles
mean [metabolism] of turtles
mean [vision] of turtles
(count turtles) / (initial-population)
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A.2 | Base sugar allocation

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00000000000000000011111111122222222233333322222222
00000000000000000011111111222222223333333333222222
00000000000000000111111112222222333333333333332222
00000000000000000111111112222223333333333333333222
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