ODD Lakeland 2

I) Overview	I.i Purpose	*I.i.a What is the purpose of the study?* The purpose of this model is to demonstrate in a simple integrated model the consequences of different cognitive processes on outcomes of a social-ecological systems. The model is a simplified version of Jager et al. (2000) but extended with inequality aversion.
		I.i.b For whom is the model designed? The model was created as an education tool and might be of interest to scholars who develop models of social-ecological systems.
	I.ii Entities, state variables and scales	*I.ii.a What kinds of entities are in the model?* There are two stocks, namely a fish population and a gold resource. A population of agents can extract from the resources.
		I.ii.b By what attributes (i.e. state variables and parameters) are these entities characterised? The agents can fish and mine. They have skills that affect the amount of extraction per unit of time. Agents need a minimum number of fish as food. Any extra fish caught is sold at the market, and shortage of fish will be bought at the market. Agents also derive income from gold mining, which can be used to buy fish on the market (food). Agents derive utility from income and leisure (time not spend on fishing and mining).
		I.ii.c What are the exogenous factors/drivers of the model? Parameter settings of the attributes of the agents.
		I.ii.d If applicable, how is space included in the model? NA
		I.ii.e What are the temporal and spatial resolutions and extents of the model? Time is an abstract number of ticks.
	I.iii Process overview and scheduling	*I.iii.a What entity does what, and in what order?* Agents make decisions on how much time to spend on fishing and

		mining in a random order using information from the previous tick. Then those decisions are implemented and the consequences are calculated for the resources and the utilities of the agents.
II) Design Concepts	II.i Theoretical and Empirical Background	*II.i.a Which general concepts, theories or hypotheses are underlying the model's design at the system level or at the level(s) of the submodel(s) (apart from the decision model)? What is the link to complexity and the purpose of the model?* The model is a variation of a predator-prey system where agents are the predator and the fish and gold resources are the prey.
		II.i.b On what assumptions is/are the agents' decision model(s) based? The consumat approach which is a multi-theoretical framework of decision making.
		II.i.c Why is/are certain decision model(s) chosen? To illustrate the consequences of different cognitive processes.
		II.i.d If the model/submodel (e.g. the decision model) is based on empirical data, where do the data come from? NA.
		II.i.e At which level of aggregation were the data available? NA.
	II.ii Individual Decision-Making	*II.ii.a What are the subjects and objects of the decision-making? On which level of aggregation is decision-making modelled? Are multiple levels of decision making included?* Agents make decisions on how to allocate their time. The evaluation is based on the utility they experience which balances income and leisure. There is only one level of decision-making, but a different cognitive process might be used dependent on the level of satisfaction and uncertainty of the agent.
		II.ii.b What is the basic rationality behind agent decision-making in the model? Do agents pursue an explicit objective or have other success criteria?

The consumat approach is a kind of bounded rationality approach, where agents use more cognitive effort if they are not satisfied, and social information if they are uncertain.

II.ii.c How do agents make their decisions?

See the model description. Based on their experienced level of satisfaction (minimum level of utility is reached) and uncertainty (outcomes are not more different than tolerated), agents will optimize, repeat, imitate or inquire. With optimization (when unsatisfied and certain) they will maximize their utility, with repetition (when satisfied and certain) they will repeat the decision of last tick, with imitation (when satisfied and uncertain) they will copy what similar others do, and with inquiring (when unsatisfied and certain) they will copy what others do if that is expected to do better than repetition of current time allocation. Agents will update their expectations only during optimizing and inquiring.

II.ii.d Do the agents adapt their behaviour to changing endogenous and exogenous state variables? And if yes, how?

Yes if this affects their satisfaction and uncertainty since it will change the way they make their decisions.

II.ii.e Do social norms or cultural values play a role in the decision-making process?

Not explicitly. In the inequality aversion setting one may argue that cultural values are included.

II.ii.f Do spatial aspects play a role in the decision process?

No

II.ii.g Do temporal aspects play a role in the decision process?

Agents look only one tick ahead.

II.ii.h To which extent and how is uncertainty included in the agents' decision rules?

Uncertainty is defined by the relative difference of the expected and experienced utility. Agents have a tolerance level for uncertainty and if agents are uncertain they use social information, but not when they are certain.

	II.iii Learning	*II.iii.a Is individual learning included in the decision process? How do individuals change their decision rules over time as consequence of their experience?* No individual learning takes place in this version of the model. Agents change their decision rules over time when there is a change in satisfaction and/or uncertainty. The updating of agents' expectations during optimizing and inquiring can be interpreted as an implicit type of learning.
		II.iii.b Is collective learning implemented in the model? No
	II.iv IndividualSensing	*II.iv.a What endogenous and exogenous state variables are individuals assumed to sense and consider in their decisions? Is the sensing process erroneous?* Resource levels, which are assumed to be measured with great precision.
		II.iv.b What state variables of which other individuals can an individual perceive? Is the sensing process erroneous? Agents observe time allocation of others and know their skill levels.
		II.iv.c What is the spatial scale of sensing? NA
		II.iv.d Are the mechanisms by which agents obtain information modelled explicitly, or are individuals simply assumed to know these variables? Explicitly in terms of imitation and inquiring to collect info on time allocation used by other agents.
		II.iv.e Are the costs for cognition and the costs for gathering information explicitly included in the model? The consumat approach assumes only more costly options if unsatisfied and/or uncertain.

II.v IndividualPrediction	*II.v.a Which data do the agents use to predict future conditions?* They calculate expected utility. They assume the future decisions of others the same as last time.
	II.v.b What internal models are agents assumed to use to estimate future conditions or consequences of their decisions? The future decisions of others are the same next tick as current tick.
	II.v.c Might agents be erroneous in the prediction process, and how is it implemented? Agents might be incorrect since the information is not updated when they repeat or imitate, or due to stochastic event in fish catch.
II.vi Interaction	*II.vi.a Are interactions among agents and entities assumed as direct or indirect?* Direct
	II.vi.b On what do the interactions depend? How time allocation is decided upon.
	II.vi.c If the interactions involve communication, how are such communications represented? NA
	II.vi.d If a coordination network exists, how does it affect the agent behaviour? Is the structure of the network imposed or emergent? NA
II.vii Collectives	*II.vii.a Do the individuals form or belong to aggregations that affect and are affected by the individuals? Are these aggregations imposed by the modeller or do they emerge during the simulation?* NA
	II.vii.b How are collectives represented? NA

	II.viii Heterogeneity	*II.viii.a Are the agents heterogeneous? If yes, which state variables and/or processes differ between the agents?* Skill levels in fishing and mining, as well as threshold levels when agents are satisfied and certain.
		II.viii.b Are the agents heterogeneous in their decision-making? If yes, which decision models or decision objects differ between the agents? Yes, since decisions depend on individual satisfaction and uncertainty.
	II.ix Stochasticity	*II.ix.a What processes (including initialisation) are modelled by assuming they are random or partly random?* Fish catch experience random event defining the size of the catch. Initialization of skills and thresholds.
	II.x Observation	*II.x.a What data are collected from the ABM for testing, understanding and analysing it, and how and when are they collected?* Using behaviorspace we collect data from resource size, income, utility, gini coefficient, pollution level, time allocations and which cognitive processes are used.
		II.x.b What key results, outputs or characteristics of the model are emerging from the individuals? (Emergence) Increasing variability of skills lead to more overharvesting (given the same mean skill) and more inequality. But if we include inequality aversion, a higher penalty of inequality reduces overharvesting and inequality.
III) Details	III.i Implementation Details	*III.i.a How has the model been implemented?* Netlogo 6
		III.i.b Is the model accessible, and if so where? Openabm address

III.ii Initialisation	*III.ii.a What is the initial state of the model world, i.e. at time t = 0 of a simulation run?* The default setting assumes a time allocation that leads to long-term sustainable use of the resource, namely 39% of the time fishing and 0% gold mining.
	III.ii.b Is the initialisation always the same, or is it allowed to vary among simulations? In the results presented the initialization may only affect the random generation of skill and threshold attributes of the agents if one includes variability.
	III.ii.c Are the initial values chosen arbitrarily or based on data? They are based on theoretical consideration to illustrate the consequences of behavioral assumptions.
III.iii Input Data	*III.iii.a Does the model use input from external sources such as data files or other models to represent processes that change over time?* No.
III.iv Submodels	*III.iv.a What, in detail, are the submodels that represent the processes listed in 'Process overview and scheduling'?* ***Resources:*** The fish population follows a traditional logistic growth function with a growth rate r, and a carrying capacity K. Each time step the fish population will experience a reduction of the stock due to harvesting activities of the agents. $\Delta Fish = r * Fish * (1 - Fish / K) - harvest$ Harvest is formulated in line with classical models in bioeconomics (Clark, 1976) and is a combination of effort (X_i), fishing skill of the agent (q^F) and the size of the fish stock (Fish). We also assume there is individual variability in the catch of the fisher by multiplier the harvest of each agent times a random number from the normal distribution n(1,σ). $$harvest = \sum_{i=1}^{n} q_i^F \cdot X_i^F \cdot Fish \cdot n(1,\sigma)$$

The carrying capacity of the fish population, K, depends on the level of pollution from gold mining in the lake. The higher the concentration of pollution, the lower the carrying capacity.

K = 100 * (1 – Pollution)

The concentration of pollution in the lake decreases by the amount of gold that is mined and slowly breaks down over time (α is removal rate).

ΔPollution = Mined / 100 – α * Pollution

The level of gold in the mine depends on the amount that has been mined.

ΔGold = - Mined

Where the amount of gold mined depends on time spend on mining, the skill set of the agent for mining and the amount of resources still available.

$$Mined = \sum_{i=1}^{n} q_i^m \cdot X_i^M \cdot Gold$$

The agents

In the default version of the model we assume agent solve the time allocation problem using the traditional Cobb-Douglas function balancing the benefits from consumption and leisure, given budget constraints.

Consumption is assumed to be directly related to income, and leisure is the fraction of time not spent on fishing and mining (1 - X_i^M - X_i^F). Agents allocate time so that they maximize utility.

$$U(X_i^M, X_i^F) = (Income)^{\gamma} \cdot \left(1 - X_i^M - X_i^F\right)^{1-\gamma}$$

Income is defined by the earnings from mining and selling fish minus the costs of buying fish on the market if the demand for food, $Fish_D$, is not met.

IF $X_i^F \cdot q_i^F$ · Fish < $Fish_D$
Income = $q_i^M \cdot X_i^M$ · Gold - p · ($Fish_D$ – $X_i^F \cdot q_i^F$ · Fish)
Else
Income = $q_i^M \cdot X_i^M$ · Gold +p · ($X_i^F \cdot q_i^F$ · Fish - $Fish_D$)

Satisficing behavior and social influence

So far we assumed agents allocate their time to maximize their expected utility. We now will apply the consumat approach (Jager et al. 2000) and consider that the agents do not strive to maximize their utility. Instead they will use different decision heuristics dependent on how satisfied they are and how uncertain they are.

An agent is satisfied if the utility derived is higher than a minimum value U_{min}. Uncertainty refers to not receiving the outcome that the agent expected. Uncertainty is therefore defined as

$$Unc = \|E[U] - U\| / E[U]$$

Where E[U] is the expected level of utility. An agent is uncertain if Unc is higher than Unc_{max}. We now have four different situations in which an agent uses a different heuristic to make a decision.

Optimizing ($U<U_{min}$ and $Unc < Unc_{max}$)
The agent is not satisfied but also not uncertain. In this situation the agent will spend time to explore all options and choose the option that maximizes utility. The agent will also calculate E[U] that will be used to calculate uncertainty.

Repetition ($U<U_{min}$ and $Unc < Unc_{max}$)
The agent is satisfied and not uncertain, and will repeat the time allocation from the previous time step.

Inquiring ($U<U_{min}$ and $Unc < Unc_{max}$)
The agent is not satisfied and uncertain, and will compare the expectation of the utility of the time allocation of similar others and the expected utility of continuing past time allocation. The agent will follow the time allocation that is the highest expected utility. In our default model we assume that similar other agents are defined by being within a 10% difference of the skills of the agents[1]. The agent also will update the expected utility.

Imitation ($U<U_{min}$ and $Unc < Unc_{max}$)
The agent is satisfied and uncertain. The agent will follow the

[1] Of course it is possible to consider alternative definitions of similar others such as members in a social network.

actions of the similar others.

Social needs

During the last 20 years substantial understanding has been derived how people value inequality (Cooper and Kagel, 2012). Most individuals prefer outcomes with less inequality. We include a simple penalty to income that is different from the mean of the population. This perceived income is defined as follows:

$$Income^{P} = Income - \beta \cdot ABS[Income - \ Mean\ Income_{other}]$$

Where β is the level in which agents will penalize inequality. The utility function is now defined as

$$U(X_i^M, X_i^F) = (Income^P)^{\gamma} \cdot \left(1 - X_i^M - X_i^F\right)^{1-\gamma}$$

We varies the variability of skills in the population and the value of β and see whether inequality aversion impact the outcomes of the agents.

III.iv.b What are the model parameters, their dimensions and reference values?

Table 1: Parameters of the model

Parameter	Description	Default values
N	Number of agents	100
X_i^F	Fraction of time fishing	[0,1]
X_i^M	Fraction of time mining	[0,1]
$1 - X_i^F - X_i^M$	Fraction of time spend on leisure	[0,1]
R	Regrowth rate fish population	0.1 per tick
K_0	Initial carrying capacity fish population	100 ton
q_i^F	Catchability: fishing skill of agent	0.1 / N
q_i^M	Mineability: mining skill of agent	0.05 / N
$Fish_D$	Demand for fish by agent	1/N
P	Price for fish on the market	1 $/ton
Γ	Elasticity	0.5
Σ	Variability	0.05
Α	Removal rate	0.01

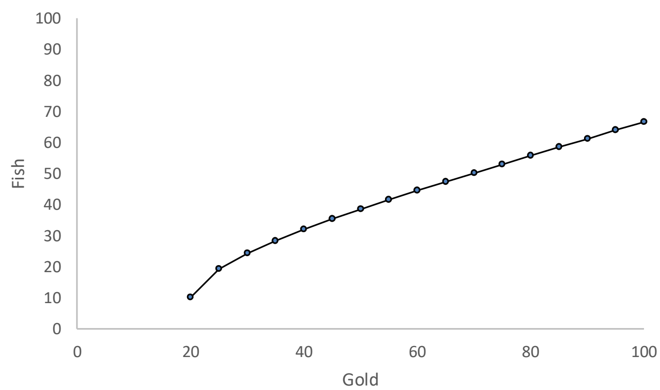
III.iv.c How were the sub-models designed or chosen, and how were they parameterised and then tested?

They are variations of well-known theoretical models. We can calculate the theoretical equilibria for the case agents are selfish and rational:

Solution 1: Agent spend time fishing:
X_i^M=0
$X_i^F = (F_D \cdot (1-\gamma) + \gamma \cdot q_i^F \cdot Fish)/(q_i^F \cdot Fish)$

Solution 2: Agent spend time mining:
$X_i^M = (\gamma \cdot (q_i^M \cdot Gold + (1-\gamma) \cdot p \cdot F_D)/(q_i^M \cdot Gold)$
X_i^F = 0

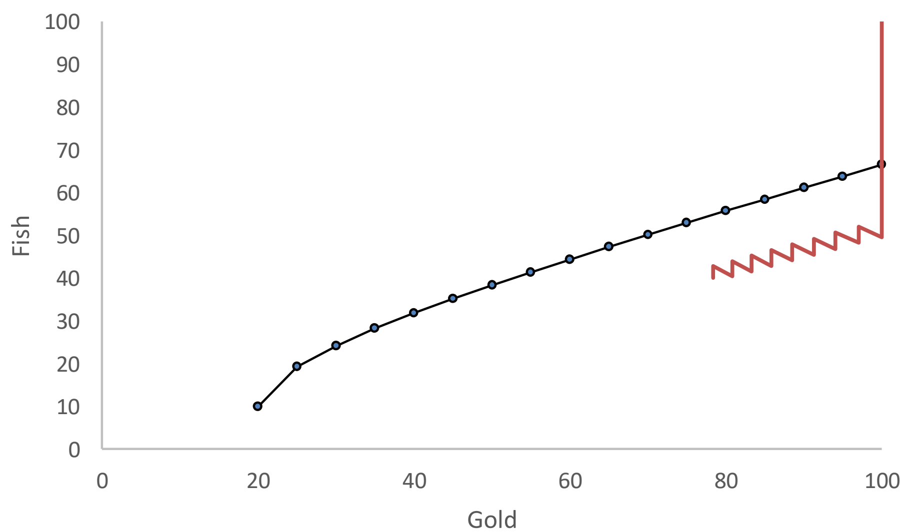
Hence agents will fish or mine (bangbang strategy). This leads to a model dynamic like the following phase diagram:



Where the line show the points where agents are indifferent to fish or mine. The system depletes the resources until (with current parameter settings) gold resource is about 20 units and fish resource is about 10 units. At that long term equilibrium there is no more mining and a modest level of fishing.

Basic analysis

Because the model has discrete time steps, a limited number of options of time allocation and a discrete number of agents, the simulated trajectory does not follow the theoretical solution. When we find an optimal time allocation we use steps of 0.1 in adjusting the time allocation instead of infinitely small steps. This leads agents to make somewhat coarser steps through the system and as shown in the figure below. We see a zigzag nature of the resource that indicates that the agents shift between fishing and mining. At a certain point fishing does not deplete the resource to a level that makes mining more desirable again. At that point a long-term equilibrium is reached.



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Jager W., M.A. Janssen, H.J.M. De Vries, J. De Greef and C.A.J. Vlek (2000) Behaviour in commons dilemmas: *Homo Economicus* and Homo *Psychologicus* in an ecological-economic model, *Ecological Economics* 35(3): 357-380