Documentation of the Rhino EMT's Political-Ecological Simulator Using the Dahlem ABM Documentation Protocol

Timothy C. Haas, Lubar School of Business,
University of Wisconsin-Milwaukee, United States
haas@uwm.edu

See Wolf et al. (2013) for the Dahlem ABM documentation protocol. The section and subsection titles below, follow this protocol.

1 Overview

1.1 Rationale

Conservation policies need to be based on reliable predictions of the effect that different policies might have on a managed ecosystem. Models can provide such predictions. One way to model such a political-ecological process to build submodels of all ecosystem-impacting groups and a submodel of the managed ecosystem. Then, have these submodels interact with each other through time. Express a proposed policy by applying its opportunities and constraints to the group submodels. Evaluate the effectiveness of this policy by observing how the ecosystem submodel responds to the sequence of actions issued by the policy-manipulated groups.

1.2 Agents

The most relevant agents for the case of rhino poaching in South Africa are

- Poachers
- Wildlife trafficking middlemen
- Rhino horn consumers in China and Vietnam
- Anti-poaching units

1.3 Other entities

An individual based model (IBM) is used to model the managed ecosystem. Here, this is the ecosystem that host rhinos within the Kruger National Park (KNP) and those South African private ranches that keep rhinos. Both regions are spatially partitioned into a small number of patches.

1.4 Boundaries

Rhino horn demand is unlimited as long as the price is below a pre-set reserve price. Ecosystem vegetation over time is a seasonal function whose parameters have been exogenously fitted to historical KNP rainfall data.

1.5 Relations

Antipoaching units have law enforcement authority over poachers. Poachers complete cash transactions with middlemen, and middlemen in turn, complete cash transactions with rhino horn consumers in Asia. Poachers interact with the ecosystem by shooting rhinos.

1.6 Activities

Poachers either poach rhinos or refrain from doing so. Antipoaching units either shoot poachers, arrest poachers, or refrain from doing either. Rhino horn consumers in Asia either purchase rhino horn from middlemen or refrain from doing so.

2 Design Concepts

2.1 Time, activity patterns and activation schemes

The political-ecological system simulator is based on a bulletin board (also referred to as a *blackboard* message posting architecture. A typical simulation run is over three years with a time step of one week. Each group submodel reacts to an action directed towards itself by another group by posting on the bulletin board a decision option selected from a pre-specified, finite set of options.

2.2 Interaction protocols and information flows

The simulator operates as follows. First, a seed *action message* is posted to the bulletin board. This message consists of the time, the actor's name, the target's name, and the BCOW action code (see Haas (2011, ch. 8)). Next, each group reads this message and, after determining their preferred action-target combination, posts this reaction to the seed message. Time is incremented to the next time point and each group reads these newly-posted messages and computes their own optimal action-target combination by conditioning on the values in the message. These optimal action-target combinations are then posted to the bulletin board. When all groups have posted their action message or messages and the ecosystem influence diagram (ID) has posted updated expected values of its output nodes, the time variable is incremented to the next time point and this process is repeated (see Figure 1).

This message posting algorithm allows feedback loops through time to emerge without need for additional model structure.

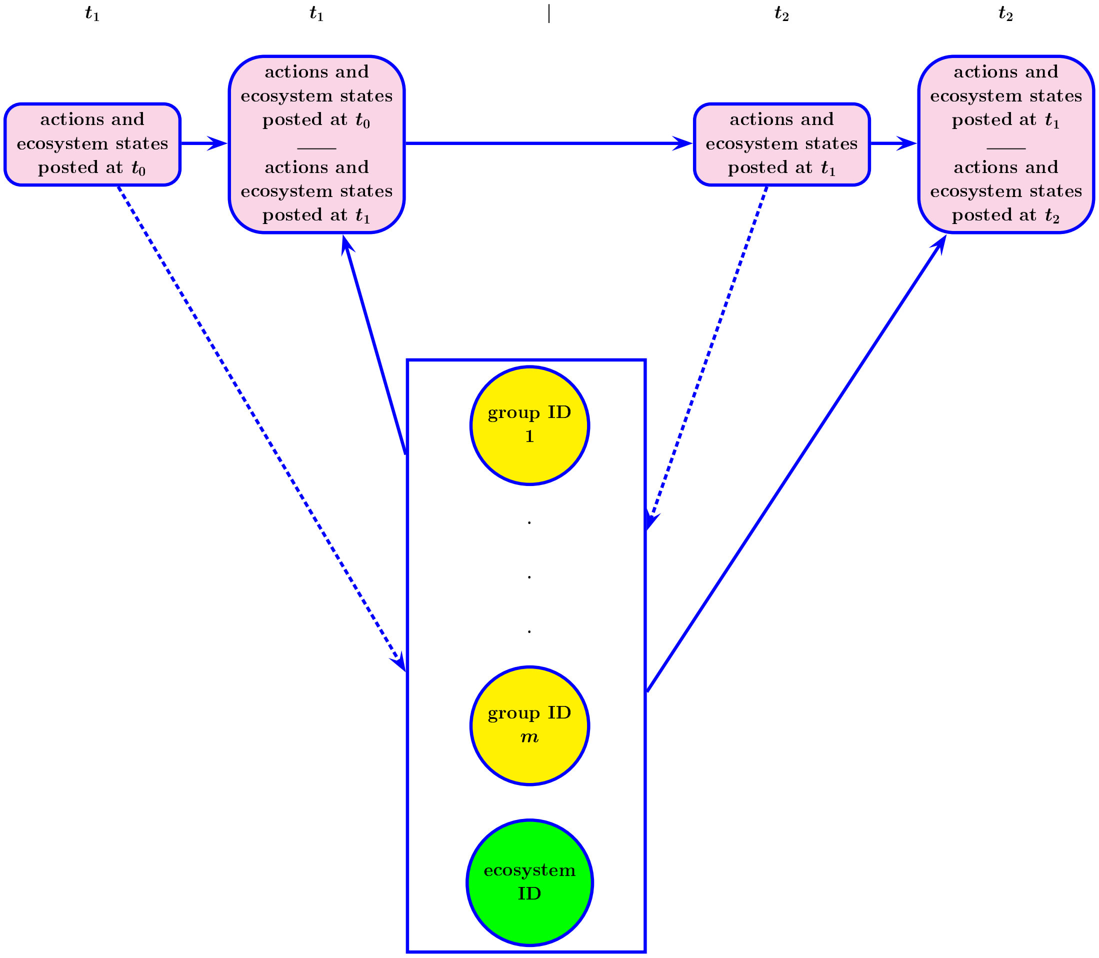

Figure 1: Sequential updating scheme of an Interacting Influence Diagram (IntIDs) model consisting of m groups and an ecosystem. At each time point, the bulletin board (top row) contains actions messages and ecosystem state messages posted to it at the indicated times. Messages are read from the bulletin board (dashed arrows), and added to the bulletin board (solid arrows).

2.3 Forecasting

At each time step, each group selects a decision that they forecast will maximize their utility in the immediate future. This forecast is performed by taking into account what actions have just been directed at them and then, for each decision option, computing the expected utility (called here, their `Overall Goal Attainment`) they would receive if they implemented that option. This forecast then, is maximum utility decision making conditional on the immediate past using an internal, possibly inaccurate model of the world.

2.4 Behavioural assumptions and decision making

- Political actors or *groups* interact with an ecosystem in a *political-ecological system*. Groups act to reach economic, militaristic, and political goals but hold internal, possibly distorted perceptions of other groups and the ecosystem. Groups interact with each other and with the ecosystem through time.

- A group's decision making and an ecosystem's responses are simulated with IDs (bayesian belief networks with deterministic input nodes). Each group is an agent. A separate ID contains an Individual-Based Model of the ecosystem. Here, a rhino population dynamics model of about 9,000 animals.

- This set of temporally interacting IDs is called an Interacting IDs (IntIDs) model.

2.5 Learning

Submodel parameters are not modified during the course of a simulation run. Hence, the IntIDs model does not learn from past events. And, new decision options are not developed within submodels during a simulation run.

2.6 Population demography

All group IDs persist in the model. No new group IDs are added during a simulation run. All rhinos in the ecosystem submodel either die of old age or are shot. Rhinos can be born. These birth-death processes are stochastic.

2.7 Levels of randomness

Stochastic simulation is used to approximate the marginal probability distribution of each node in an ID an compute the expected utility of the Overall Goal Attainment node under each combination of inputs and proposed decision option. Decisions are posted to the bulletin board with no further randomness. To avoid decision patterns due to the order in which group IDs read the bulletin board, the order in which group IDs read the bulletin board is randomized each time step. The ecosystem submodel is a stochastic Individual Based Model (IBM). Simulation is used to approximate the expected value of the managed species' abundance node (here, rhino). This expected value is posted to the bulletin board.

2.8 Miscellaneous

Group IDs can issue up to two decisions per time step if there are at least two actions directed at them during the last time step.

3 Functional Specification

3.1 Description of agents and other entities, action and interaction

The **id** modeling and analysis software system runs a JAVA^{TM} executable form of this model.

3.1.1 Poachers group submodel

For the purpose of evaluating different scenarios, we define a decision option of *take legal employment* in our poachers group decision making diagram but represent the current lack of such jobs by setting hypothesis values for the chance of achieving career goals from such employment to very low values. To represent the decision to not poach when there are no other alternatives such as taking legal employment, we add the decision option *do nothing.*

A poacher's sole audience is his immediate and extended family (Figure 2). Poachers are pursuing the four goals of making a living, supporting their immediate and extended family, raising their social standing in their community, and avoiding prosecution. The goals of making a living, supporting family, and raising their social status are very similar and interlinked. Hence, for simplicity, we aggregate these goals into one goal: the pursuit of a career. Therefore, the poacher decision making diagram contains only two goals.

Poachers sell their rhino horn by physically trading the rhino horn for cash during an interaction with a middleman.

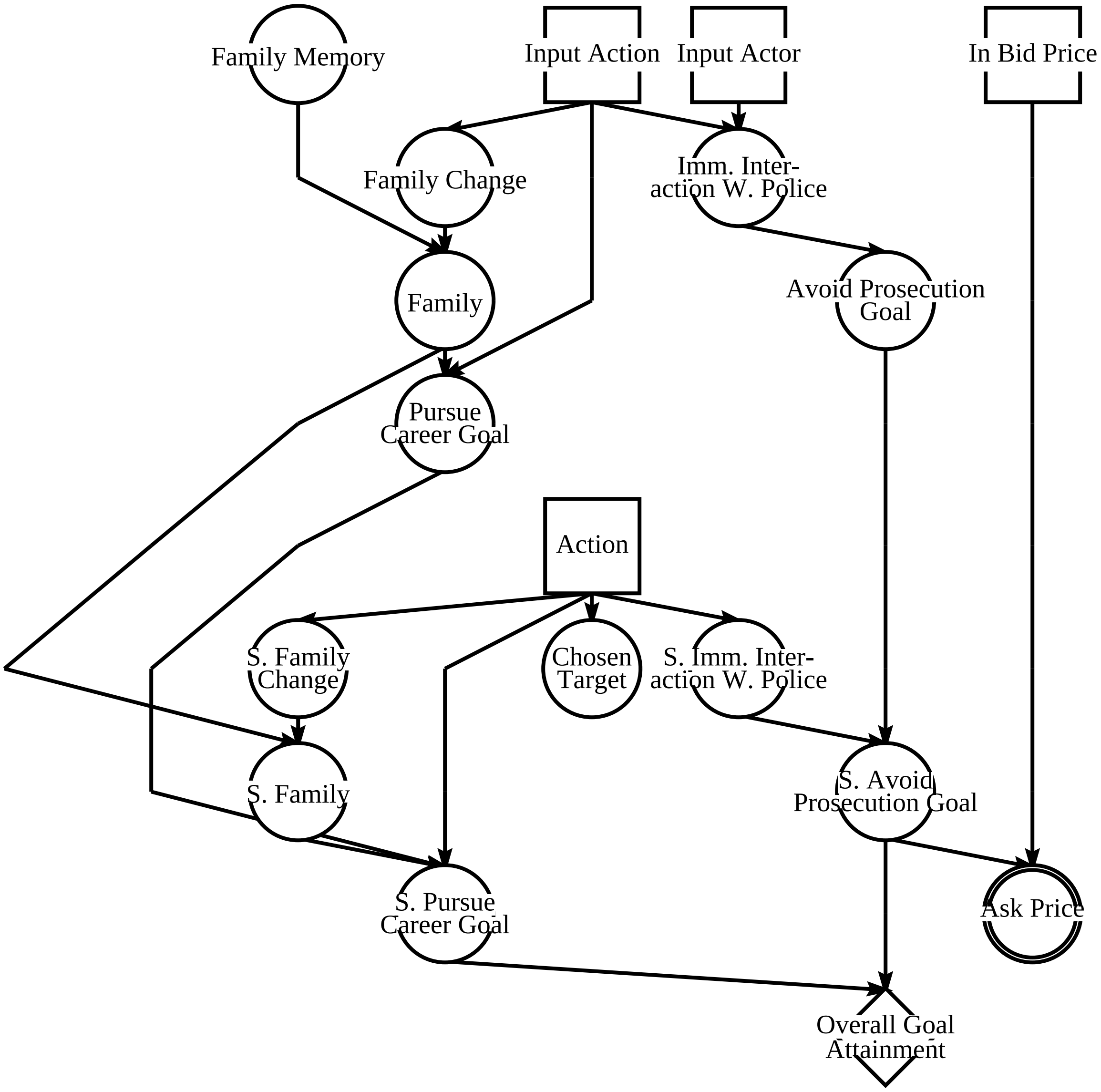

Figure 2: Poachers have two conflicting goals: **Pursue Career**, and **Avoid Prosecution**. They have one audience: **Family**. Square: decision options; Diamond: overall feeling of goal attainment. A decision (action) node along with the Situation Goal nodes affects Scenario Goal nodes.

3.1.2 Aggregated submodel of first- and second-tier middlemen

Middlemen are a diverse group of businessmen, former poachers, and diplomats (Montesh 2012, Smillie 2013). Subsistence is not a goal for these upper middle class individuals. Rather, the profit motive is their sole personal goal for engaging in this illegal activity. The middleman group's single audience is the trader group (Figure 3). Middlemen are pursuing the goals of (a) making a profit, (b) satisfying rhino horn demands made by the traders, and (c) avoiding prosecution.

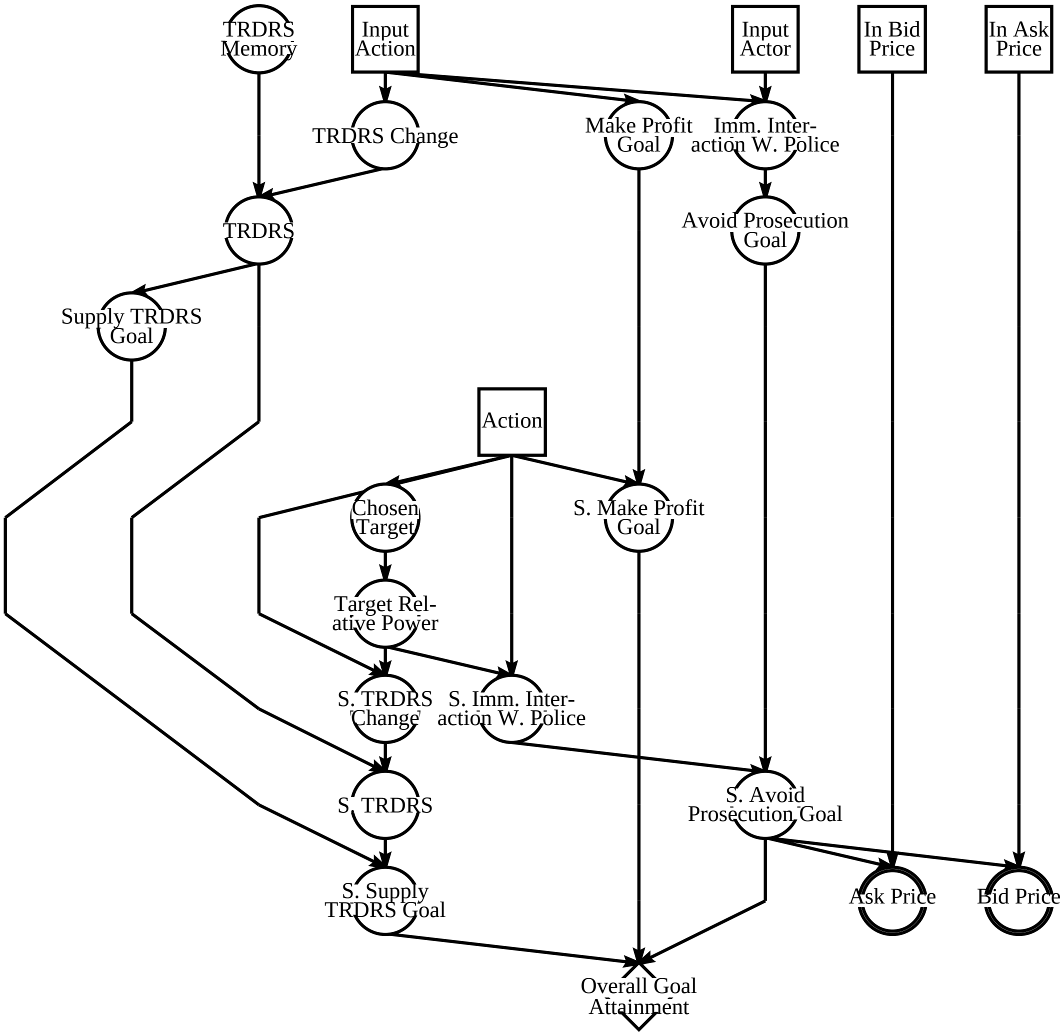

Figure 3: Middlemen decision making diagram.

3.1.3 Anti-Poaching units

This submodel represents the aggregate behavior of anti-poaching units operated by SANParks within KNP, those units of the South African National Defense Force (SANDF) stationed within KNP, and outside-KNP provincial, and national police forces including the South African Police Service (SAPS), and the South African Revenue Service (SARS).

Perceptions of the ecosystem's state held by anti-poaching units are represented by a single `Rhino Prevalence` node, see Figure 4. This node is influenced by the expected value of the ecosystem influence diagram's `Rhino Abundance` node. Specifically, `Rhino Prevalence` takes on the values *none*, *few*, and *many* and has a cumulative logit distribution with the one explanatory variable, E[`Rhino Abundance`]. Values of this variable, having been previously posted to the bulletin board (see Haas (2011, ch. 2)) by the ecosystem influence diagram, are read from the bulletin board each time this decision making diagram computes a decision.

The South African government is this group's only audience. Anti-poaching units are pursuing two goals: (a) protect the environment, and (b) increase their staff and budget. The latter goal is justified in Haas (2011, ch. 7).

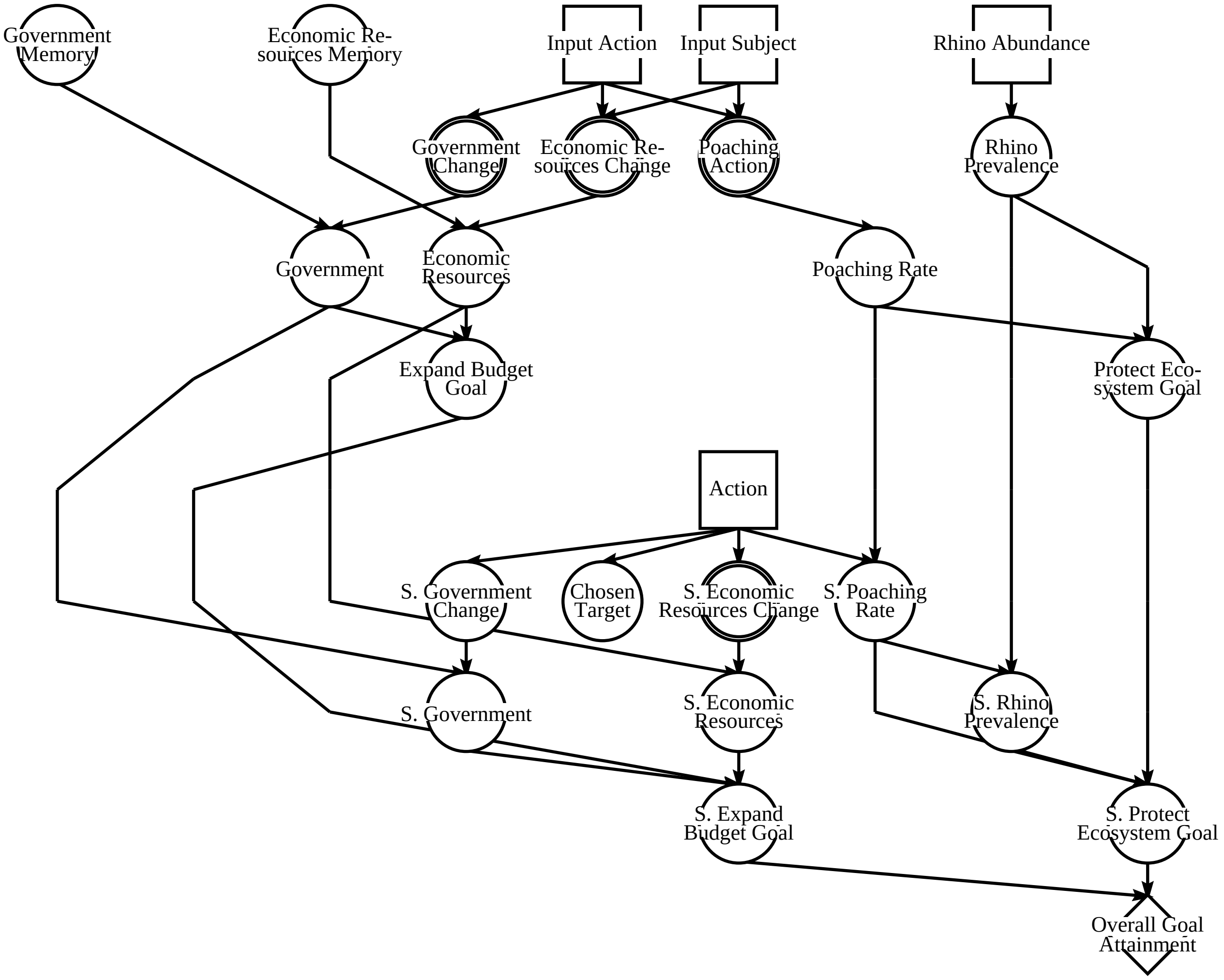

Figure 4: Anti-poaching units decision making diagram.

3.2 Interacting traders and consumers submodel

The decision making diagram of retail traders interacting with rhino horn consumers models the bid-ask spread that traders contend with (Figure 5). This diagram also contains nodes for representing traders' pricing decisions and re-supply requests that are both functions of rhino horn consumer decision making. In effect then, this decision making diagram is an agent-based submodel of rhino horn consumers in Asia interacting with a number of competing rhino horn traders.

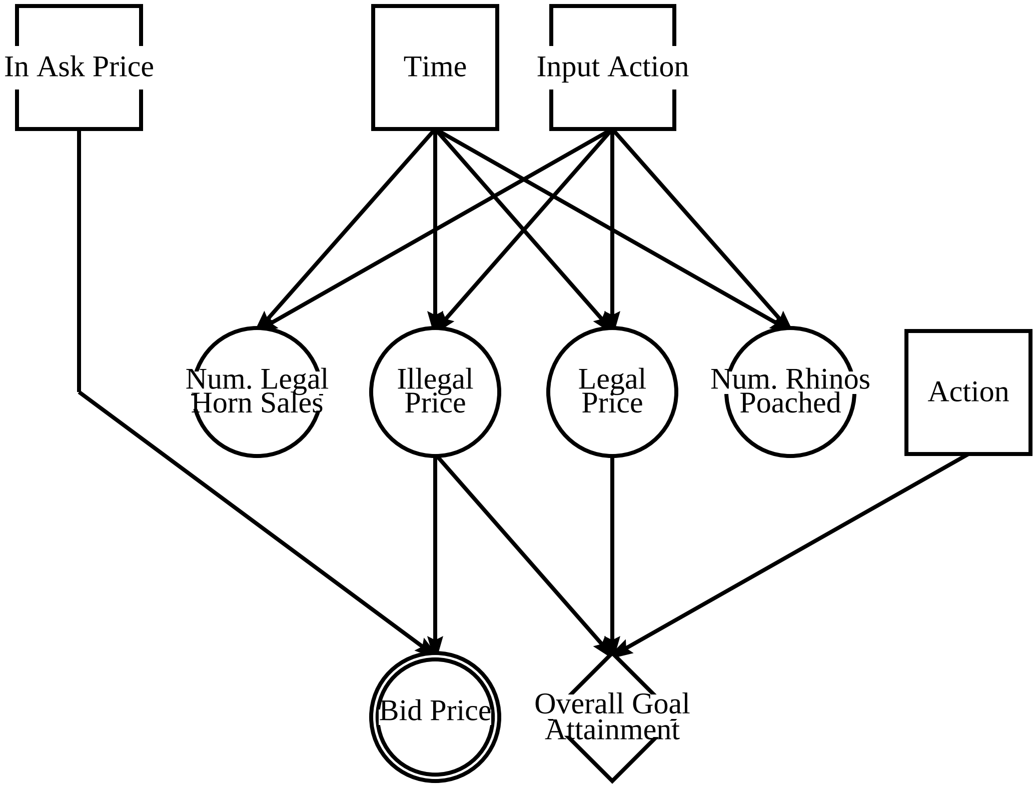

Figure 5: Decision making diagram of rhino horn traders interacting with rhino horn consumers.

An agent-based economic model represents individual firms as agents and individual consumers as agents. One cycle consists of each trader making decisions about product re-supply and product pricing that maximizes their individual utility. Also during this cycle, each consumer makes decisions about entering a market, and once entered, purchasing decisions that maximize their individual utility. Time is incremented, and another cycle is executed.

There are two *basic goal functions* in the following update rules. Collectively, these functions represent a firm's single goal of increasing its profits. These goal functions are updated through a reinforcement learning algorithm adapted to economic ABMs by L. Tesfatsion, an early advocate of economic ABMs. Specifically, the price goal `q-response` and the production capacity goal, `c-response` are updated using price and production capacity experiences at the previous time point. Actual pricing and production capacity decisions are stochastic in order to represent as noise all effects on the firm's decision making not captured by the model.

1. Compute the expected new price. First compute the response to the price goal function:

$$\texttt{q-response}_{t-1} = \texttt{price}_{t-1}\left[1 - \frac{\texttt{capacity}_{t-1} - \texttt{nmsold}_{t-1}}{\texttt{capacity}_{t-1}}\right]. \tag{1}$$

   To see "what the market will bear",

$$\texttt{q-response}_{t-1} = 1.01\texttt{price}_{t-1} \text{ if } \texttt{capacity}_{t-1} = \texttt{nmsold}_{t-1}. \tag{2}$$

2. Compute the expected value of the new price:

$$\mu_t = (1 - \texttt{learn-rate})\mu_{t-1} + \texttt{learn-rate} \times \texttt{q-response}_{t-1}. \tag{3}$$

3. The new price is found by sampling once from a normal distribution with mean μ_t and a standard deviation of \$200.

4. The net revenue is:

$$\texttt{netrev}_t = \texttt{nmsold}_{t-1}(\texttt{price}_{t-1} - \texttt{unit-cost}). \tag{4}$$

5. The response to the production capacity goal function is:

$$\texttt{c-response}_t = \texttt{netrev}_t - \texttt{netrev}_{t-1}. \tag{5}$$

6. The production capacity decision constant is:

$$\texttt{q-prodcap}_t = (1 - \texttt{learn-rate})\texttt{q-prodcap}_{t-1} + \texttt{learn-rate} \times \texttt{c-response}_t. \tag{6}$$

7. The production capacity decision Binomial distribution probability is:

$$p_c = \frac{\texttt{q-prodcap}_t + \texttt{maxnetrev}}{2 \times \texttt{maxnetrev}}. \tag{7}$$

8. Production capacity is reduced, left unchanged, or increased according to the following rules. First, let D be a binomially distributed random variable with $n = 2$, and probability of success equal to p_c. Sample once from this distribution. If $d = 0$, $\texttt{prodcap}_t = \texttt{prodcap}_{t-1} - 1$. If $d = 1$, $\texttt{prodcap}_t = \texttt{prodcap}_{t-1}$. If $d = 2$, $\texttt{prodcap}_t = \texttt{prodcap}_{t-1} + 1$ up to this trader's maximum production capacity. Both traders have a maximum production capacity of $150kg$ of rhino horns per week. Because the horns from an adult rhino weigh approximately $5kg$, this value represents 30 rhinos per week. In 2013, an average of 20 rhinos were poached per week across South Africa. Hence, this maximum is ten rhinos above the 2013 weekly average.

9. Reduce the production capacity of the illegal trader in proportion to the effectiveness of anti-poaching operations as follows. Let N_p be binomially distributed with $n = \texttt{prodcap}_t$ and probability of success equal to p_a. The probability p_a is set to a number close to 0.0 if anti-poaching operations are very effective at curbing poaching. Sample once from this binomial distribution to find n_p, the actual number of rhinos poached this week in spite of anti-poaching operations.

10. Model the effect of additional anti-poaching funds donated by SEAR traders by reducing n_p by 5% if n_p is greater than 25.

11. Model the effect of population growth on the Asian continent on the number of potential rhino horn consumers. Most consumers of rhino horn live on the Asian continent.

    The initial consumer population is created as follows. To represent the assumption of insatiable demand at current (illegal) production levels, consumers are created as necessary to purchase all rhino horn poached under the maximum poaching rate of 30 rhinos per week across South Africa (20 in KNP, and 10 on the ranches). Because each rhino horn weighs on average $5kg$, these numbers are multiplied by 5. Therefore, in the year 2014, the potential number of consumers is set to 300 (5×60). This value is increased in proportion to the entries in a table of Asian continent population projections – up to a maximum of 325 in the year 2033.

For the case of a legal trading scheme operating in parallel to the illegal trade, this consumer pool is doubled. Because demand for rhino horn in the near future is predicted to be about four times current sales, doing so is well-within current demand forecasts. The supply of legally-traded rhino horn would be sourced from stockpiles and/or shavings from live rhinos.

By a "consumer" we mean a group composed of a number of real-life individuals. It is not atypical for an individual to spend \$2,000 on a single purchase of rhino horn powder. At the per-kilogram prices mentioned above, this would be between 33 and $57g$ of rhino horn. Other individuals may purchase other amounts of rhino horn. In our model however, one of our "consumers" always buys exactly one kilogram of rhino horn at each purchase event. Hence, one of our "consumers" represents approximately 18 to 30 real-life individuals. By doing so, we ignore the variability in the amount of purchased rhino horn and in-effect, lump approximately 18 to 30 real-life purchase events into one purchase event. Hence, our submodel's purchase event time series should be viewed as the aggregate behavior of groups of approximately 18 to 30 real-life individuals.

12. Consumer behaviors start with the decision to enter the rhino horn market or not. If there is a media campaign aimed at potential rhino horn consumers that delivers a message that rhino horn has no medicinal value, some of the potential consumers may decide to not try to purchase rhino horn. This media campaign effect is represented as follows. Let n_{pc} be the number of potential consumers each week. Let p_m be the effectiveness of a horn-is-not-medicine media campaign run in the country where the consumers live. If p_m is close to 1.0, the chance that a randomly chosen potential consumer will decide to buy rhino horn is close to zero. Let N_c be binomially distributed where there are n_{pc} trials, and the success probability is $1 - p_m$. Sample once from this distribution to find n_c, the number of consumers for that week who enter the market for rhino horn.

13. Simulate rhino horn purchases. Each consumer buys one kilogram of rhino horn from the trader offering it at the lowest price as long as this price is below the consumer's

reserve price of $60,000. Because the illegal trader maintains a buffer stock of rhino horn, the number of kilograms of rhino horns the illegal trader sells each week need not equal five times the number of rhino horns poached the previous week.

3.2.1 Rhino population dynamics IBM

We model the age, gender, energetic budget, location, and status of each individual rhino living and dying in enclosed patches and hence also model interactions of these rhinos with their environment – namely seasonal fluctuations in food availability; and interactions with each other through the effects of their spatial density on their birth and mortality rates. The IBM executes the following schedule of actions each week.

1. Delete all rhinos set to *dead* during the previous time step.
2. Find within-patch populations.
3. Increment each rhino's age.
4. Up to a rhino's mean energy budget (*meb*) or juvenile energy budget (*jeb*) value, a rhino's energy budget is updated in the following manner:
    (a) Compute the *vegetation ratio*:

    $$\texttt{vratio} = 0.01\left[\frac{\texttt{netveg}_t}{\boldsymbol{wfi} \times \texttt{nmindiv}_t + 1} - 1\right] \tag{8}$$

    where $\boldsymbol{wfi}$ is a rhino's weekly food intake, $\texttt{nmindiv}_t$ is the number of patch residents at time t, and $\texttt{netveg}_t$ is the available vegetation within the patch at time t.

    (b) Compute the amount of energy change:

    $$\texttt{ec} = \frac{2}{1+\exp(-\texttt{vratio})} - 1. \tag{9}$$

    (c) If $\texttt{netveg}_t < \boldsymbol{wfi} \times \texttt{nmindiv}_t$, do the following for each patch resident. First, sample once from V, a random variable uniformly distributed over the unit interval to obtain v. Then, if $v < 0.4$, $\texttt{energy}_t = \texttt{energy}_{t-1} + \texttt{ec}$.

    (d) If $\texttt{netveg}_t > \boldsymbol{wfi} \times \texttt{nmindiv}_t$ then for each patch resident, $\texttt{energy}_t = \texttt{energy}_{t-1} + \texttt{ec}$.

    (e) For each rhino having $\texttt{energy}_t = 0$, draw a realization from V to obtain v. Set this rhino to *dead* if $v < 0.1$.

5. Set to *dead*, any rhinos having an age greater than le.

6. Simulate food deficit and animal density effects on birth and mortality rates. See the Supplementary Materials of Haas and Ferreira (2016) for how this is modeled within our IBM.

7. Process poaching actions. From the economic submodel, read m, the number of rhinos that are to be poached for this week. Randomly select m mature rhinos and set them to *dead*.

8. Legal hunting on ranches . The hunting off-take from the ranch population is 50% of the oldest males annually. An "old male" is defined to be a male older than the 90th percentile of male ages on the ranch. Find these individuals as follows.
   (a) Sort all male ages, and then locate the 90th percentile age.
   (b) Form a group of males older than this threshold age. Say there are `nm-old-males` individuals in this group.
   (c) If `nm-old-males` is positive, compute `nmhunt`, the number of individuals to hunt (kill) each week with `floor`$(0.5 \times$ `nm-old-males`$/52)$. Otherwise, set `nmhunt` to zero.
   (d) Randomly select `nmhunt` individuals from the old male group and kill them.

9. Sell some ranch-kept rhinos. This off-take is from all age classes and both genders. Each year, one-fourth of the exponential growth rate is removed from ranches. The exponential growth population model is $N_t = N_0 \exp(rt)$ where N_t is abundance at the end of the time interval, t (measured in years), N_0 is the initial population size, and r is the exponential growth rate. Then, for a given r, the selling off-take each week is $0.25r/52$.

10. For each mature female rhino, create one new rhino if (a) its $\texttt{time-since-last-birth}_t$ is greater than *intercalv*, (b) some males are residents of the female's patch, and (c) the female's energy is greater than *meaneb*.

11. For each female not giving birth,

$$\texttt{time-since-last-birth}_t = \texttt{time-since-last-birth}_{t-1} + 1. \tag{10}$$

12. Update patch membership by randomly moving rhinos into different patches within subregions that possess nonzero net vegetation.

13. Update the net vegetation of each patch. First, find the amount of new vegetation at this time point from the above set of vegetation predictions. Second, find the amount of left over vegetation at this time point as

$$\texttt{vegleftover} = \texttt{netveg}_t - \boldsymbol{wfi} \times \texttt{nmindiv}_t. \tag{11}$$

    Finally, sum these values of left over vegetation across the previous 36 weeks. If this sum is negative, reset it to zero.

3.3 Initialization

An initial action from one of the group IDs is specified in the model's input file. Initial rhino population sizes are specified in the **id** source code file, `IBMcalcs.java`.

3.4 Run-time input

A model **id** input file (.id) is used to make a simulation run with the command `idalone somename.id` where `somename.id` is the model input file name. This input file, in turn, lists the submodel .id files and associated parameter value files (somename.par). A unique pair of .id and .par files is needed for each group being modeled. A separate pair of .id and .par files is used to define the managed ecosystem.

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