1D Deforestation Model with Agribusiness Dynamics

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1 Initialization

Let $N \in \mathbb{N}$. This code takes some parameters and is supposed to generate spatial-temporal series of a 1 dimensional, discrete grid with N entries[1] for these variables: Deforestation $(D_{nt})_{t=0}^{\infty}$, emissions $(O_{nt})_{t=0}^{\infty}$, Rents $(R_{nt})_{t=0}^{\infty}$ and Agribusinesses locations $(S_{nt})_{t=0}^{\infty}$.

The most important decisions to initialize the model are

- Where the Agribusiness begins. This should be a $1 \times N$ matrix with entries 1 meaning that there is an agribusiness in that plot and 0 if there is not;
- Which plots are protected/unprotected. Also a $1 \times N$ matrix with 1 meaning protected and 0 unprotected;
- The initial deforestation. This is at least equal to the initial Agribusiness.
- Productivity is also a $1 \times N$ matrix. **Its entries need to be bigger than** 1.
- $\rho, \sigma > 1$

The following is an example on how to set up these variables.

```
Agribusiness = zeros(1, N, Tmax); Agribusiness(1,end,1) = 1; % Agrinusiness starts in one of the vertices
D = zeros(1, N, Tmax); D(1,end,1) = 1; % If the Agribusiness is there, then it is deforested.
O = zeros(1, N, Tmax); O_aux = rand(1,N); O(:,:,1) = D(1,1,1).*O_aux;
R = zeros(1, N, Tmax);

A = 2.*ones(1,N);          % Productivity > 1
F = 2*ones(1,N);           % Homogeneous deforestation cost
L = zeros(1,N); L(1,1:N/2) = 1;% Legal status (1 = protected, 0 = unprotected)
                             % everything is protected (static case)
w = wage * ones(1,N);        % Constant wage
```

[1]You can think of it as a $1 \times N$ matrix.

2 Simulation Loop

The model iterates over time steps to update land use, emissions, and agribusiness expansion. Before going into the loop, it is important to calculate the neighbors vector, as it will be important in the computation of the profits in the future.

```
neighbors = cell(1, N);
for i = 1:N
    idx = [i-1, i+1];
    idx(idx < 1 | idx > N) = [];
    neighbors{i} = idx;
end
```

After this last snippet, a for loop going from $t = 1$ to $t = T_{\max}$. In each of these steps, we must update our 4 variables of interest. The first one that concerns us is R_{nt}, as it is required to determine both deforestation and the Agribusiness dynamics. Remember that the expression that rules over rents in plot n at period t is

$$\Psi\{S, n\} - \Psi\{S\} \geq R_{nt} \geq \max\left\{\varrho_1 F + \varrho_2 w_n - \varrho_3 A_{nt} - \frac{w_n}{1-\beta}, \frac{A_{nt} - w_n}{1-\beta}\right\} \tag{1}$$

The upper bound of this inequality is Agribusinesses profits and the lower bound is the farmer selling price. The idea is to set values of R_{nt} as an weighted average of the bounds. The weights will determine the bargaining power of each side. This next code calculates the upper bound

```
for i =1:N
    if Agribusiness(1,i,t) == 1
        continue;
    end
    pft = 0;
    ContAgri = sum(Agribusiness(1,neighbors{i},t)); % Counting the S
    for k = neighbors{i} % Computing profits in contiguous sites
        if Agribusiness(1,k,t)==1
            term1 = profit(A,ContAgri+1,k);
            term2 = profit(A,ContAgri,k);
            pft = pft + term1 - term2;
        end
    end
    DiffProfit(1,i) = pft + profit(A,ContAgri+1,i);
end
```

Note that rents will not be calculated in sites that are already Agribusinesses as this computation would be useless. For each $n = 1, \cdots, N$, the loop begins by checking if the site is an Agribusiness and skipping to the next site if it is the case. After that, we store the number of contiguous sites that are Agribusinesses in the ContAgri object and for each of them (whose positions are stored in neighbors(n)), we compute that **difference of profits**. In the end of the loop, we add the profit of plot n. This process should make the rents higher when distance to the closest Agribusiness decreases. Forests contiguous to an Agribusiness and located in unprotected sites should be the most valuable, ceteris paribus.

The lower bound is a trivial matrix calculation.

```
FarmersProfit = max(q1*F+q2*wage-q3*A-wage/(1-beta),
    (A-wage)/(1-beta));

R(1,:,t) = 1.*DiffProfit + 0*FarmersProfit; % Full bargaining
    power to the Agribusiness
```

Next, we turn to deforestation. Farmers make deforestation choices based on discounted earnings of each plot. Legal status will play an important role in these decisions. The value functions for each legal status are coded in different files and appear here as functions. The main difference between then is that the value of unprotected land depends on rents, because there is a possibility of selling it.

A plot will be deforested if the following happens: (i) it has not been deforested and (ii) is value is bigger than zero.

```
Vu = value_u(A,R(1,:,t),F);
Vp = value_p(A,F);

Du = L == 0 & D(1,:,t) ~= 1 & Agribusiness(1,:,t) ~= 1 & Vu > 0;
Dp = L == 1 & D(1,:,t) ~= 1 & Agribusiness(1,:,t) ~= 1 & Vp > 0;
```

Finally, we update deforestation, emissions and the Agribusiness. The latter is the most complex. Firstly, every deforested plot that is not an Agribusiness has the chance of (i) obtaining property rights and (ii) being sold to the Agribusiness. The first thing happens with probability π, and the latter happens if the difference in profits (values of Ψ) is superior to R_{nt}. If a land does not get the property rights in one period, it will have another shot in the next. Every deforested plot is eventually sold to an Agribusiness with probability 1.

```
% Updating Deforestation
D(1,:,t+1) = D(1,:,t) + Du+Dp;

% Updating Emissions
O(1,:,t+1) = (Dp+Du) .* O_aux;
% Updating the Agribusiness
Candidates = D(1,:,t) - Agribusiness(1,:,t); %plots that can gain
    property rights
PP = Candidates ==1 & rand(1,N) < pi & L==0; %plots that have
    earned property rights
NewAgri = PP==1 & DiffProfit >= R(1,:,t);
Agribusiness(1,:,t+1) = Agribusiness(1,:,t) + NewAgri;
```

3 Some exercises

This section will show some parameters, results and thoughts on 1D applications of the model.

3.1 Everything protected and A decreasing (static model).

This exercise will present no dynamics, as $\pi = 0$. Indeed, without the Agribusiness purchasing new territories and influencing the values of the contiguous plots via R_{nt}, all deforestation will be made in $t = 1$. We set all territories to be unprotected and productivity to be decreasing in n. We initiate the agribusiness in the left vertex of the grid, i.e, in the one with the highest productivity.

Table 1: Agribusiness in one vertex

Variable	Value	Description
N	15	Number of spatial plots
T_{max}	25	Number of time periods
β	0.10	Discount factor)
α	0.75	Land productivity parameter
π	0	Probability of acquiring property rights
T_{lag}	2	Time producing at low productivity
δ	1	Demand shifter
τ	1.2	Transport cost
w_n	1	Wage level
σ	1.5	Elasticity parameter
$\bar{S}$	6	Σ parameter
p_I	1	Investment price parameter
ρ	1.5	Interest rate

```
A = linspace(3.1,1.1, N);
F = 1.8*ones(1,N);
L = zeros(1,N); L(1,1:N/2) = 1;
w = wage * ones(1,N);
D = zeros(1, N, Tmax); D(1,1,1) = 1;
O = zeros(1, N, Tmax); O_aux = rand(1,N); O(:,:,1) =
    D(1,1,1).*O_aux;
Agribusiness = zeros(1, N, Tmax); Agribusiness(1,1,1) = 1;
```

Figure 1 and Figure 2 shows deforestation before and after these simulations. Note that all deforestation is done in the first period, as we predicted given the lack of the Agribusiness. The Agribusiness gives life to this model. In a world in which the amount of deforested plots is constant, emissions are linear.

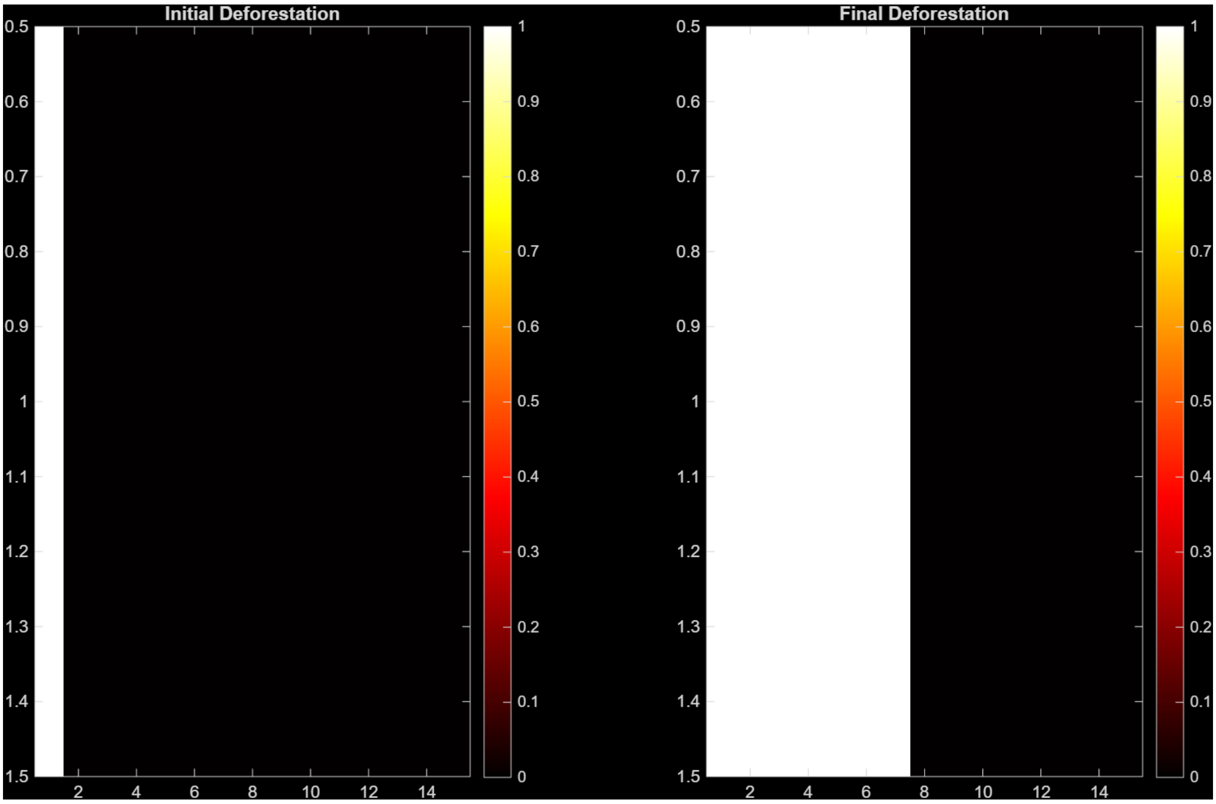

Figure 1: $\pi = 0$ and A decreasing: initial and final deforestation. $1 =$ deforested, $0 =$ not deforested

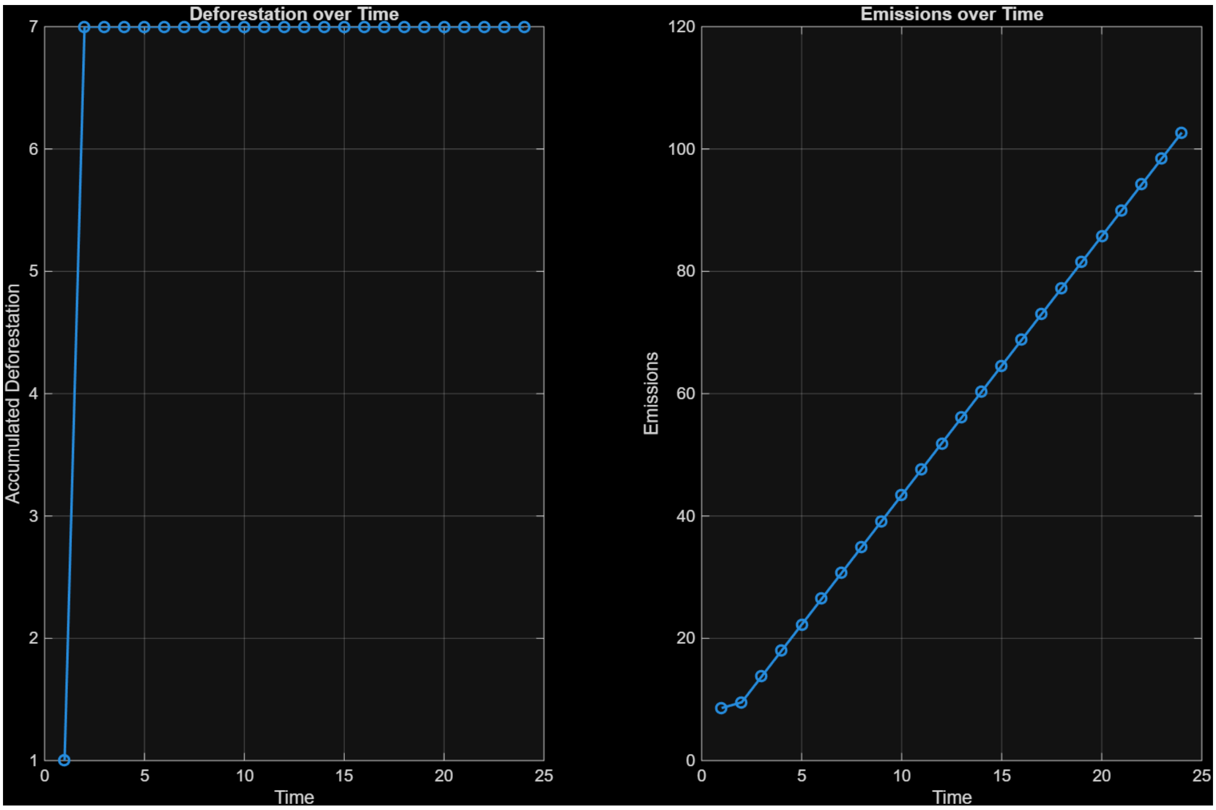

Figure 2: $\pi = 0$ and A decreasing: accumulated deforestation and emissions

3.2 Agribusiness in one vertex

Here we will see some dynamics. We begin by creating the a deforestation point in the last position of the deforestation matrix in the first period. Include the same position in the Agribusiness map. Consider a geography in each the first half positions are protected, and the last half, where the agribusiness stars, is unprotected. Table 3 shows the rest of the parameters.

Table 2: Agribusiness in one vertex

Variable	Value	Description
N	15	Number of spatial plots
$T_{\max}$	25	Number of time periods
β	0.10	Discount factor)
α	0.75	Land productivity parameter
π	0.5	Probability of acquiring property rights
T_{lag}	2	Time producing at low productivity
δ	1	Demand shifter
τ	1.2	Transport cost
w_n	1	Wage level
σ	1.5	Elasticity parameter
$\bar{S}$	6	Σ parameter
p_I	1	Investment price parameter
ρ	1.5	Interest rate

```
A = 2.*ones(1,N);          % Productivity > 1
F = 1.8*ones(1,N);          % Homogeneous deforestation cost
L = zeros(1,N); L(1,1:N/2) = 1;% Legal status
w = wage * ones(1,N);        % Constant wage
D = zeros(1, N, Tmax); D(1,end,1) = 1; % Agrinusiness starts in one of the vertices
O = zeros(1, N, Tmax); O_aux = rand(1,N); O(:,:,1) = D(1,1,1).*O_aux;
R = zeros(1, N, Tmax);
Agribusiness = zeros(1, N, Tmax); Agribusiness(1,end,1) = 1; % Agrinusiness starts in one of the vertices
```

Figure 3 and Figure 4 shows deforestation before and after these simulations. Note that the Agribusiness enters the grid over time, following the Agribusiness dynamic. Protected land is kept intact: its value is too low and cannot be influenced by the presence of the Agribusiness. Emissions have superlinear behavior.

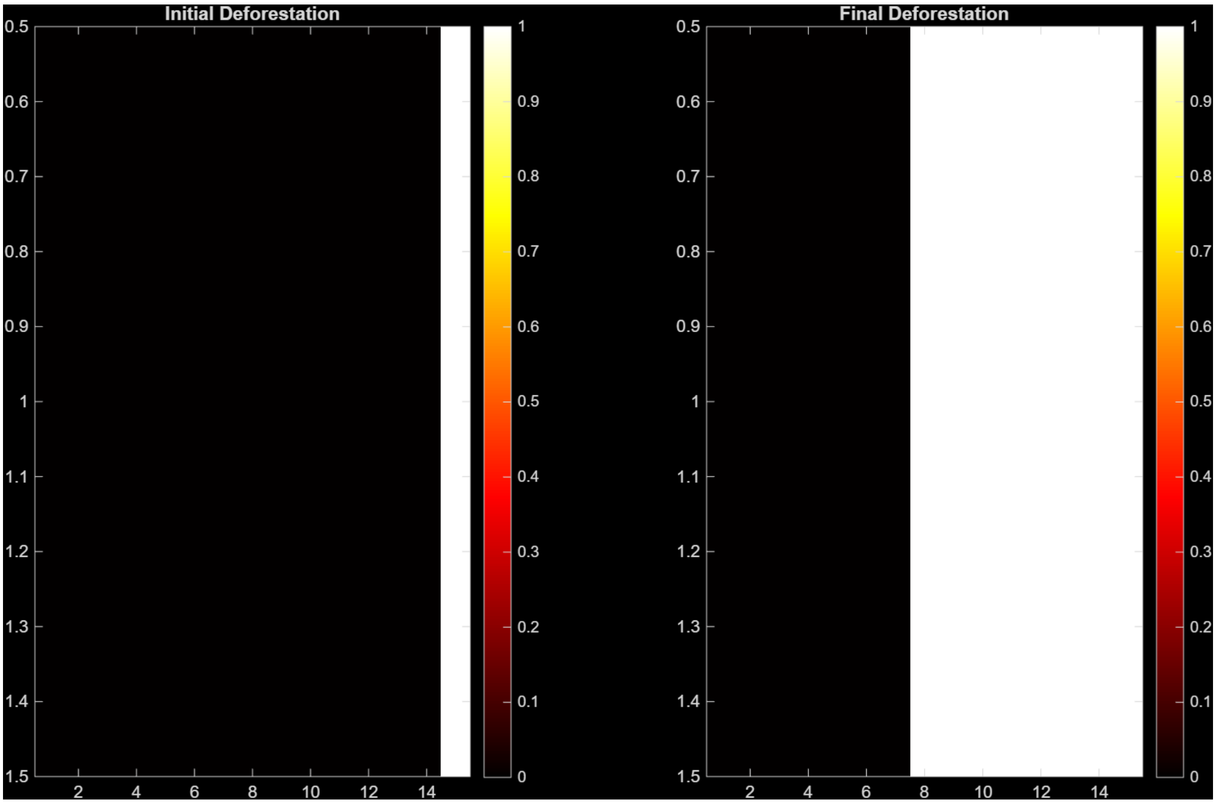

Figure 3: Agribusiness on the vertex: initial and final deforestation. 1 = deforested, 0 = not deforested

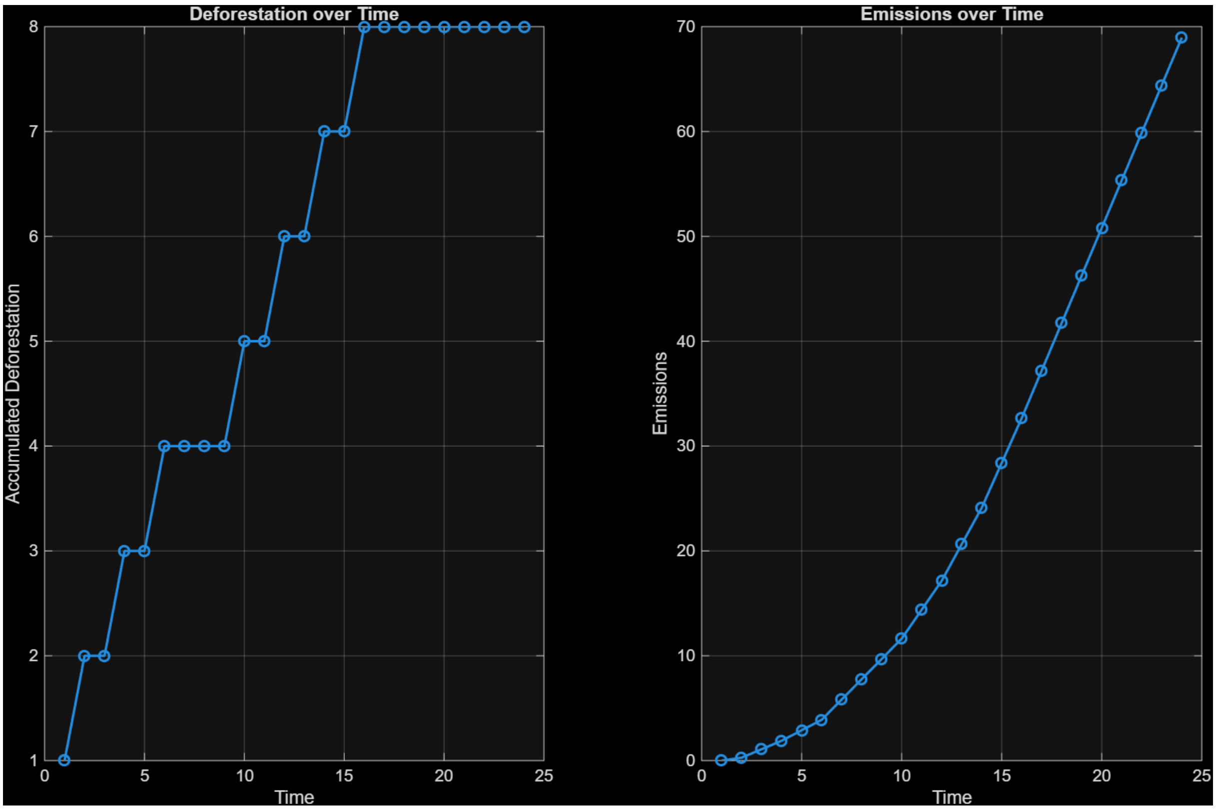

Figure 4: Agribusiness on the vertex: accumulated deforestation and emissions

3.3 Agribusiness in the middle

This time, initiate the Agribusiness in position 8 ($N = 15$) and make only two protected sites, 4 and 11. This will stop the expansion of the Agribusiness.

Table 3: Agribusiness in one vertex

Variable	Value	Description
N	15	Number of spatial plots
$T_{\max}$	25	Number of time periods
β	0.10	Discount factor)
α	0.75	Land productivity parameter
π	0.5	Probability of acquiring property rights
T_{lag}	2	Time producing at low productivity
δ	1	Demand shifter
τ	1.2	Transport cost
w_n	1	Wage level
σ	1.5	Elasticity parameter
$\bar{S}$	6	Σ parameter
p_I	1	Investment price parameter
ρ	1.5	Interest rate

```
A = 2.1.*ones(1,N);
F = 1.65*ones(1,N);
L = zeros(1,N); L(1,4) = 1; L(1,11) = 1;
w = wage * ones(1,N);

D = zeros(1, N, Tmax); D(1,8,1) = 1;
O = zeros(1, N, Tmax); O_aux = rand(1,N); O(:,:,1) =
    D(1,1,1).*O_aux;
R = zeros(1, N, Tmax);
Agribusiness = zeros(1, N, Tmax); Agribusiness(1,8,1) = 1;
```

Figure 3 and Figure 4 shows deforestation before and after these simulations. Note that the Agribusiness enters the grid over time, following the Agribusiness dynamic. Not all land is protected, but the 2 protected plot manage to stop the Agribusiness to deforest everything, even some unprotected areas.

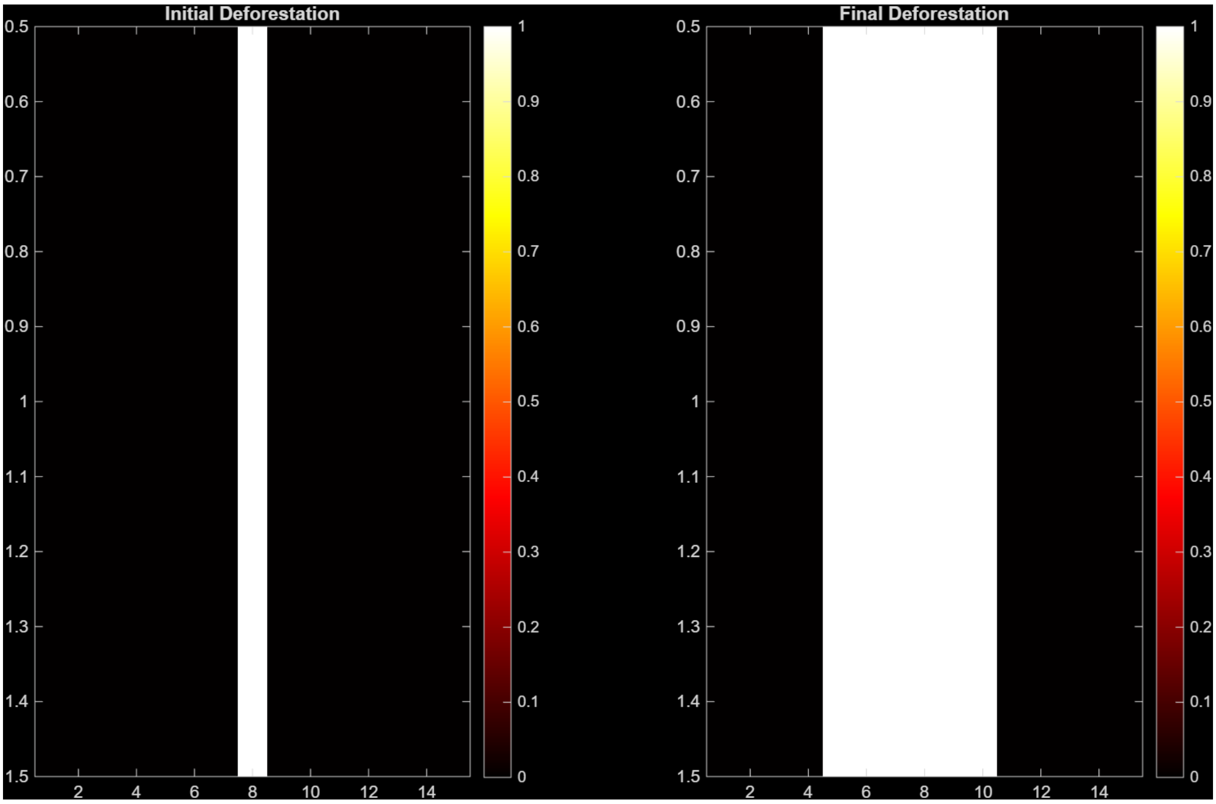

Figure 5: Agribusiness on the vertex: initial and final deforestation. 1 = deforested, 0 = not deforested

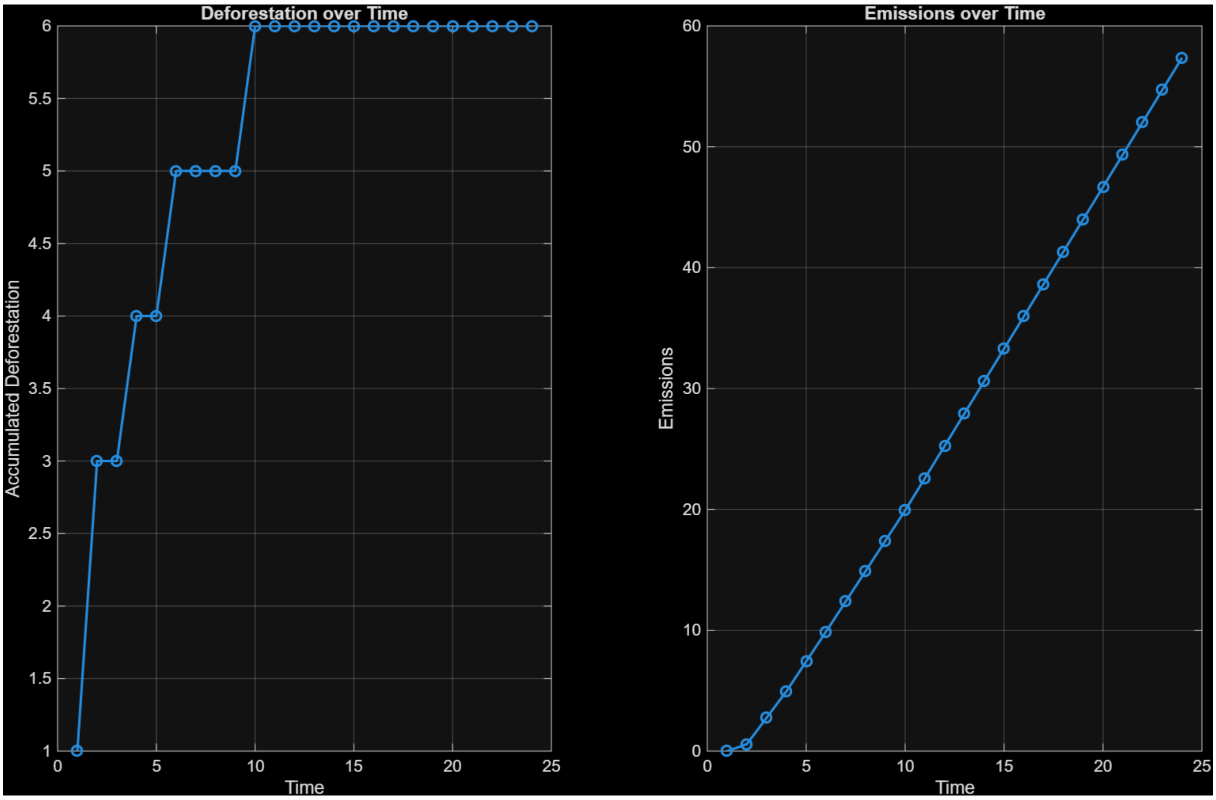

Figure 6: Agribusiness on the vertex: accumulated deforestation and emissions