Economic Approach: Application of DEB Theory to Eucalyptus Fibre Production

Ricardo Vieira, Instituto Superior Técnico, Lisbon, Portugal. 16-04-2003

Introduction

Reserve dynamics in DEB theory plays an important role being one of the particular things introduced in biological systems analysis. When we are looking for an economic system, it is usual to consider reserves as important dynamics. In an industrial system, for instance, flow regulation reservoirs are important reserves systems to consider. In an agricultural system, it is important that reserves mass at the beginning (soil mass) be equal to reserves at ending. If it is lower, we are in presence of soil erosion. In this sense it is important to adjust fertilizer quantities in order to eliminate this problem.

Other example of the importance of reserves is in the extractive industry, for instance fishing, in order to avoid stock depletion (in particular for non-renewable resources).

The aim of this essay is to apply the DEB theory to the economic system of eucalyptus (*Eucalyptus* globulus L.) production for the paper industry. I will start with some definitions about the eucalyptus production, reserves and structural mass and then I will apply the synthesizing units (SU, from now) concept to the system under analysis.

Eucalyptus is a tree, generally produced in 13 years rotations, after which it is harvested. It has as inputs the carbon dioxide (CO_2), oxygen (O_2), light, water (rain water), nitrogen (N, organic or inorganic), potassium (K), calcium (Ca), phosphorous (P) and other minerals and metals.

The environment provides water, CO_2, O_2 and light. Water is accumulated in soil and then used by eucalyptus trees. CO_2, O_2 and light have no accumulation since they are used directly from the environment.

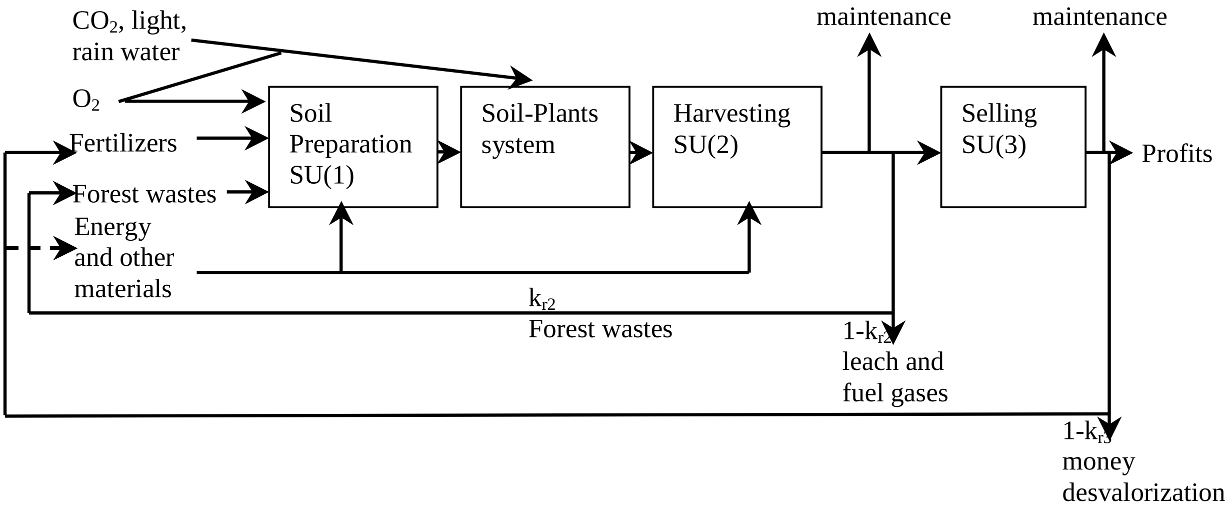
Nutrients are supplied to the plant by the soil. They are provided to the soil by fertilizers and with the decomposition of forest wastes like leaves, barks, branches and roots.

For eucalyptus production it is needed to prepare soil ploughing and introducing fertilizers and forest wastes. Then the soil is ready for eucalyptus plantation. During the growing process of the tree it is needed other fertilization operation, weeds removal and tracks maintenance, which I consider them as maintenance operations. The final operation related to eucalyptus production is harvesting. Harvesting includes all operations from eucalyptus cutting to trucks loading with the wood.

There is a flux of trees arriving the age of 13 years, and so, a flux of trees harvested. If we consider that only a rotation is running, the mass that is harvested is equal to that occurring in the year 13. Since the time needed for growing eucalyptus is held constant, the analysis can be made in terms of masses or fluxes (mass rates) as mass/time quotients.

The product of this system is a part of eucalyptus: the log (M_{w1} for mass and J_{w1} for mass rate) (and sometimes a fraction n of barks) the rest are considered as forest wastes and are reincorporated in the soil.

For this activity there are necessary machines, human labour, offices and buildings, area for eucalyptus plantation and financial capital. These factors are considered as the structural mass of the activity. For maintenance of these factors it is, therefore, needed fuels (for the machines), money (to human labour), electricity and other materials (as paper, lamps, etc.). The system is schematised on Figure 1. The



particular case of fuels is that they are only used for maintenance purposes.

Figure 1 – Simplified system of the eucalyptus production. This activity ends up with the operation of selling the logs to a pulp industry. The raw materials that enter in selling operation are only the logs and a part of eucalyptus barks. The profits obtained could be used for new machinery acquisition.

Basic Concepts

The structural "mass" is understanded as materials and installations needed for the main process (wood production) and they are not directly consumed by this. The main objective of an economic system is to increase its structural mass. Therefore, structural mass is: the buildings, the forest area, the machines, employees and the profits of it. Here "mass" is in inverted commas because it is not possible to measure it in mass units. It could have money units.

Buildings are a fixed part of a company, and they are independent of its final product. The variation in economic capital and forest area does not imply a variation in buildings (like offices and warehouses). So, their contribution to structural "mass" is constant.

Forest area (A_f) is strongly related to final product (if we consider optimal forest practices – e.g. a tree density of 1667[a] eucalyptus/ha) and it is a linear function of the area ($A_f = \alpha J_{w1}$).

Machines and human labour (N) are also functions of final product. However, they are not linear functions such as forest area: after a certain number of machines it is not possible to use all of them at the same time due to limitations related to forest area, fuels or employee's number.

---

[a] This is the optimal density for eucalyptus plantations.

Therefore, structural “mass” could be written as a function of final product.

For reserves mass it is important to make a distinction between trees mass (M_w) and log mass (M_{w1}). A tree is formed by leaves, branches, roots, barks and logs. Logs are the commercial part of eucalyptus, having the fibres to the paper industry, all the other parts of eucalyptus have no economic value and they are separated from logs (which are sold), forming the forest wastes mass (M_{FW}). The tree mass is the sum of leaves, branches, roots, barks (M_{barks}) and logs (M_{w1}) masses. The economical value of M_w is considered equal to M_{w1}. However, in real systems, it is lower due to the fact that is needed to do work to remove leaves, branches, barks and roots. Sometimes what is sold is not only the logs but also barks (due to technical limitations), although the selling price is always in terms of log mass.

Reserves result from acquiring inputs (raw-materials) that are not used instantaneously so they have to be stored. In this system, nutrients and part of O_2 are stored first in the soil and then in trees. Reserves mass (M_E) equals M_{soil} + M_w, where M_{soil} is soil mass and M_w is the trees mass. Soil mass decreases with time after fertilization have been done. Trees mass increase with time.

The SU are considered as the productive operations such as soil preparation (SU(1)), harvesting (SU(2)) and selling (SU(3)). The later two correspond to what is called in DEB theory a growth SUs.

Final product (M_{w1}) is very important because its production allows an increase in structural “mass” of the company. The relation of it with mass rejected is also an important factor since it indicates losses in potentially capital increase. Due to these two motives the analysis made pays attention to product and rejection masses.

System Analysis

SU(1)

SU(1) is in its binding phase in the beginning of each rotation. This occurs every 13 years for each parcel, so the number of machines + humans ready to prepare soil, N_o, reads

$$\frac{d}{dt}N_0 = (N - N_0)\dot{k}_x - N_0 \times \min\left(J_E, J_{FW}, J_F, J_O, \frac{1}{3}\right) \quad \text{(eq. 1).}$$

Where N is the total number of machines + human, $\dot{k}_x$ is the return rate to binding phase (1/13 years^{-1}). The second term refers to the inputs that take long to achieve the minimum quantity for the initiation of the process. 1/13 appears in order to guarantee that that process only starts after the previous rotation had been finished.

N is not linearly proportional to the final product, as it been referred before. In order to have a fixed number of machines available at the beginning of a rotation we have to consider steady state in (eq.1). In this latter case it possible to determine the material fluxes to the soil per N.

SU(2)

Making mass balances it is possible to write the following relations (eq. 2 and 4):

$$J_A = J_{Energy} + J_{FW} + J_F + J_H + J_C + J_O \quad \text{(eq. 2).}$$

Where J_A is the flux that comes in to the soil-plant system, J_{Energy} as the flux of fossil fuel used, J_{FW} as the flux of forest wastes, J_F as the fertilizers flux, J_H as rain water flux, J_C as the CO_2 mass absorbed and incorporated in eucalyptus, J_O as O_2 mass incorporated in the plant and soil.

The flux of mass that comes in to SU(2), J_{C2}, could be lower, equal or higher that J_A. This relation depends on the fertilizer mass added to the soil and the energy needed in both SUs. Fertilizer mass added to the soil can be higher, equal or lower that eucalyptus nutrient needs plus nutrients leaches. The energy fluxes, J_{Energy}, are different between SU(1) and SU(2), since they have different energy needs.

$$J_{R2} = (1-k_{r2})J_{R2} + k_{r2}J_{R2} \qquad \text{(eq. 3).}$$

Where:

$$(1-k_{r2})J_{R2} = J_{gases} + J_{leach};$$

$$k_{r2}J_{R2} = J_{FW} - nJ_{barks};$$

J_{R2} is the rejected mass; k_{r2} is the fraction of forest wastes in the rejected mass; n is the fraction of barks presented in final product related to the total barks amount.

Since all entries are functions of final product it is possible to define a vector, **m**, where:

$$J_{W1} \times m_* = J_* \qquad \text{(eq. 4),}$$

and generally

$$J_{W1} \times \mathbf{m} = \mathbf{J} \qquad \text{(eq. 5),}$$

where **J** is a vector with all mass inputs and outputs.

So, **m** is a vector that makes the relation between all fluxes and the final product flux. As an example:

$$\begin{aligned}(1-k_{r2})J_{R2} &= J_{R2} - k_{r2}J_{R2}\\ &= J_{C2} - J_{M2} - J_{W1} - J_{FW}\\ &= J_F + J_O + J_{FW} + J_C + J_{gases} - J_{W1} - 2nJ_{barks}\end{aligned}$$

They are all functions (linear) of J_{w1}, so it is possible to write:

$$(1-k_{r2})J_{R2} = J_{W1} \times m_{R2} \qquad \text{(eq. 6)}$$

SU(3)

This SU correspond to the exchange of wood logs by money. These logs have amounts of barks (due to technical limitation related to weather conditions). In this SU prices are used instead of masses. It is possible to define factors that allow the conversion between masses and prices. However, due to some economic external inputs, these factors have null values for some inputs. Instead of defining such factors, it is possible to define the factor k_{C3} (price of log per unit mass of log) that converts the log mass into its market price (P_{C3}):

$$P_{C3} = M_{W1} \times k_{C3} \qquad \text{(eq. 7),}$$

and since all inputs and outputs are related to the logs mass, it is possible to know the contribution of each input to P_{C3}. J_{C3} can be defined as the selling wood value per unit of time:

$$J_{C3} = J_{W1} \times k_{C3} \quad \text{(eq. 8).}$$

Figure 2 shows a scheme for money fluxes post SU(3).

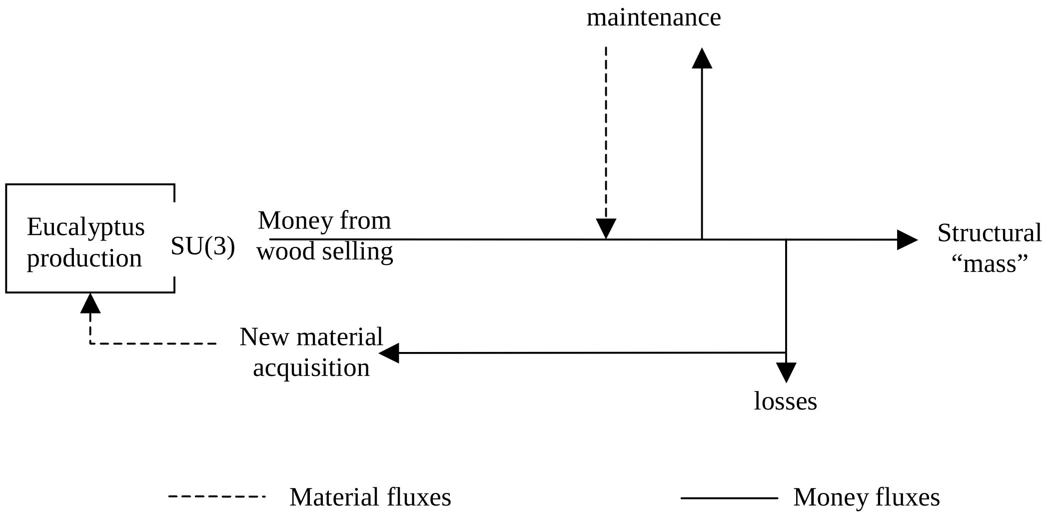


Figure 2 – SU approach for money fluxes in the economic system under analysis

In Figure 2, the flux for maintenance, J_{m3}, is the flux of money used in repairs, salaries, office materials, etc. This value is a function of J_{W1}.

The profits flux (economic capital income flux), J_{V3}, could be determined by:

$$J_{V3} = J_{C3} - J_{m3} - J_{r3} \quad \text{(eq. 9)}$$

where J_{C3} is the flux of money from wood selling, J_{r3} is the rejected money flux. Profits could be used to buy new machinery, converting one form of structural "mass" to another. The rejected value is considered to be the sum of money inflation, and the money spent on raw materials acquisition, as it is possible to see in eq. 10:

$$J_{r3} = (1 - k_{r3}) J_{r3} + k_{r3} J_{r3} \quad \text{(eq. 10),}$$

$$k_{r3} J_{r3} = J_{energy} k_{energy} + J_F k_F \quad \text{(eq. 11),}$$

where k_{energy} and k_F are conversion mass fluxes to price for energy and fertilizers respectively.

Considering specific prices <P_*> for any input *, excluding forest wastes and considering O_2, CO_2, light and rain water with null specific prices, it is possible to define the vector $\mathbf{P_{in}}$ as what was spent with each input:

$$\mathbf{P}_{in} = \begin{bmatrix} J_F \times \langle P_F \rangle \\ J_{Energy} \times \langle P_{Energy} \rangle \\ J_o \times \langle P_o \rangle \\ \ldots \end{bmatrix} \cdot \Delta t \ ,$$

if we define y_* as the mass fraction of input * that was incorporated in final product, we have a possible economic value of the loss fraction:

$$(1 - k_{r3}) J_{r3} = \mathbf{P}_{\mathbf{in}}^T \cdot [\mathbf{I} \textbf{ - } \mathbf{y}].$$

As there were made before (for SU(2)), it is possible to determine a relation between the mass fluxes of materials and the price of wood logs, defining a vector **p** where:

$$J_{C3} \times p_* = J_* \qquad \text{(eq. 12)}$$

for any flux of material *, and, more generally,

$$J_{C3}\mathbf{p} = \mathbf{J} \qquad \text{(eq. 13).}$$

The vector **p** is results from the multiplication of k_{r3} with the vector **m** defined for the SU(2). Here we can conclude that every input/output can be translated in terms of J_{C3} or J_{w1}.

Conclusions

In this essay I tried to apply the SU theory to an economic system. From this analysis it is possible to conclude that there are important similarities (e.g. the possibility for make a partition of the fluxes that comes out the SU).

An important conclusion is that it is possible to translate all mass fluxes in terms of final product and, consequently, to the profits. I tried to introduce a method for determination of the economic value of mass losses to the environment (leaches and gases from combustion).

However, to validate the DEB theory it is needed to:

- Do a much more deep analysis to the system, applying not only the SU theory but all the assumptions of DEB and compare it with real numerical values,
- Apply such an analysis to other economic systems