Biodiversity and Agriculture: Towards a Systemic Approach

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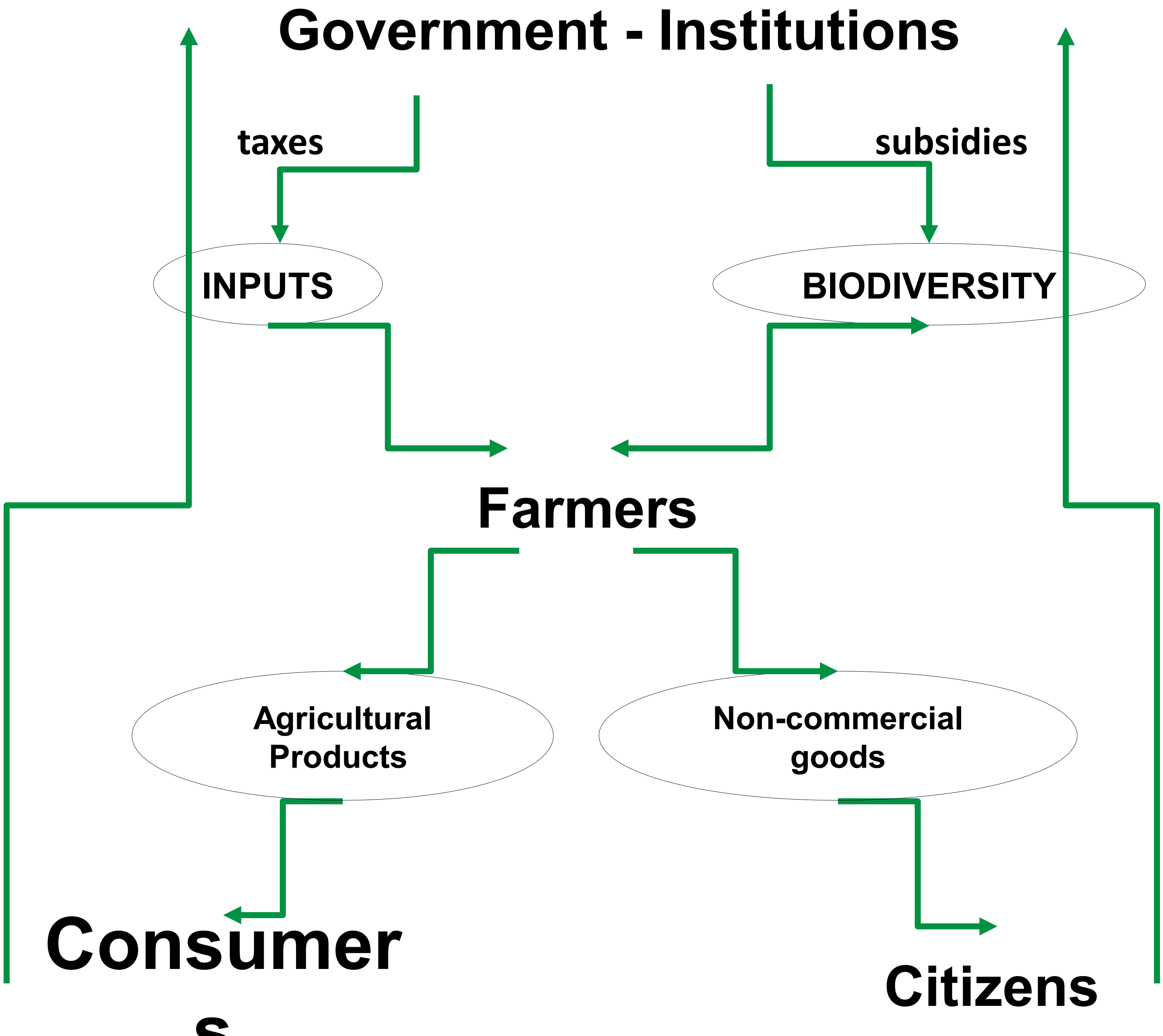
"The word "model" sounds more scientific than "fable" or "fairy tale" although I do not see much difference between them. [. . .]

The fable is an imaginary situation that is somewhere between fantasy and reality. **Any fable** can be dismissed as being **unrealistic** or **simplistic**, but this is also the fable's **advantage.**
Being something between fantasy and reality, a fable is **free** of **extraneous details** and **annoying diversions.**

In this unencumbered state, we can **clearly discern** what cannot always be seen in the real world.

On our **return to reality**, we are in possession of some sound advice or a **relevant argument** that can be used in the **real world**. We do exactly the same thing in economic theory."

Ariel Rubinstein, "*Dilemmas of an Economic Theorist*"


Government - Institutions
taxes
subsidies
INPUTS
BIODIVERSITY
Farmers
Agricultural
Products
Non-commercial
goods
Consumer
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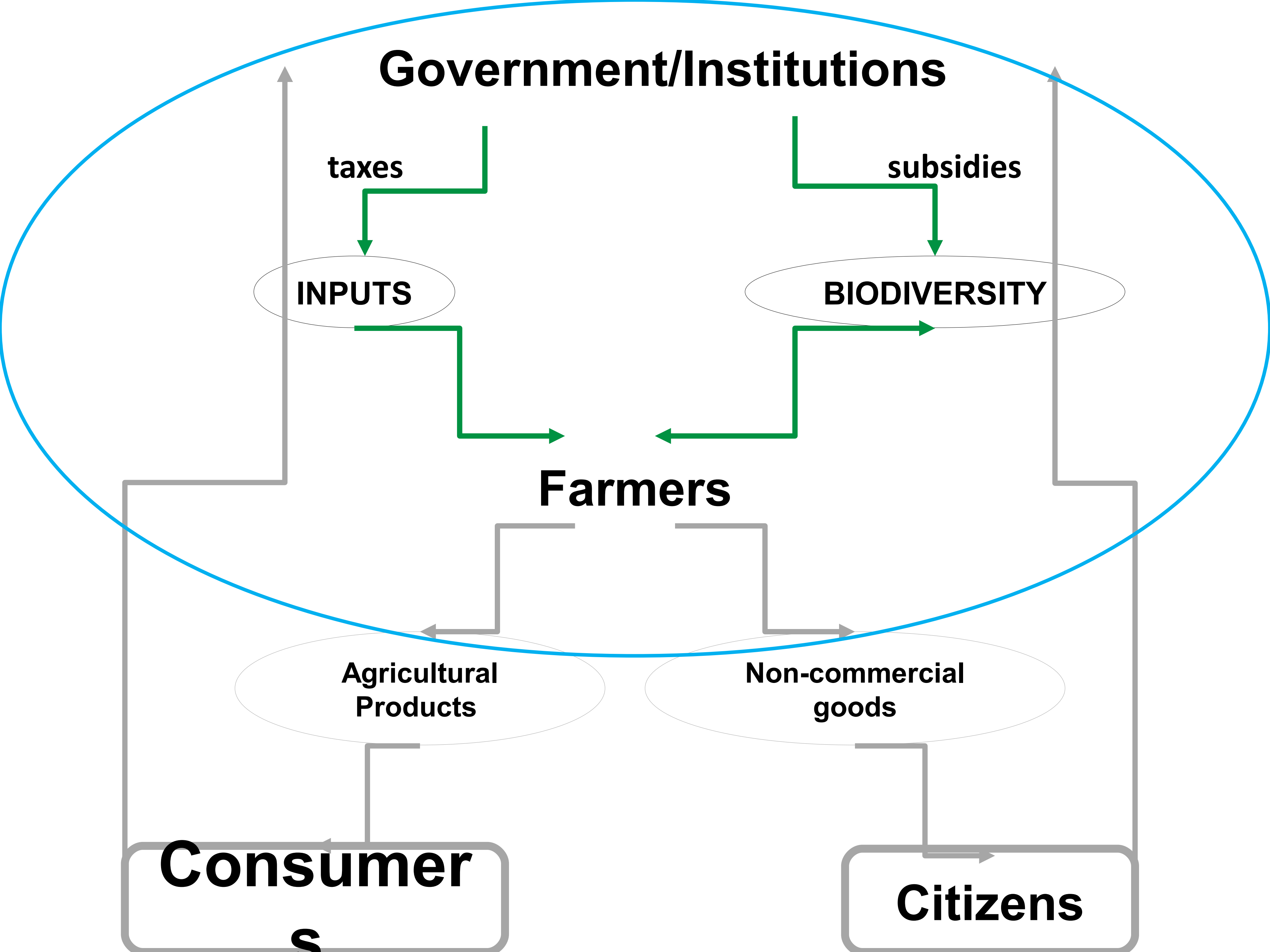
Citizens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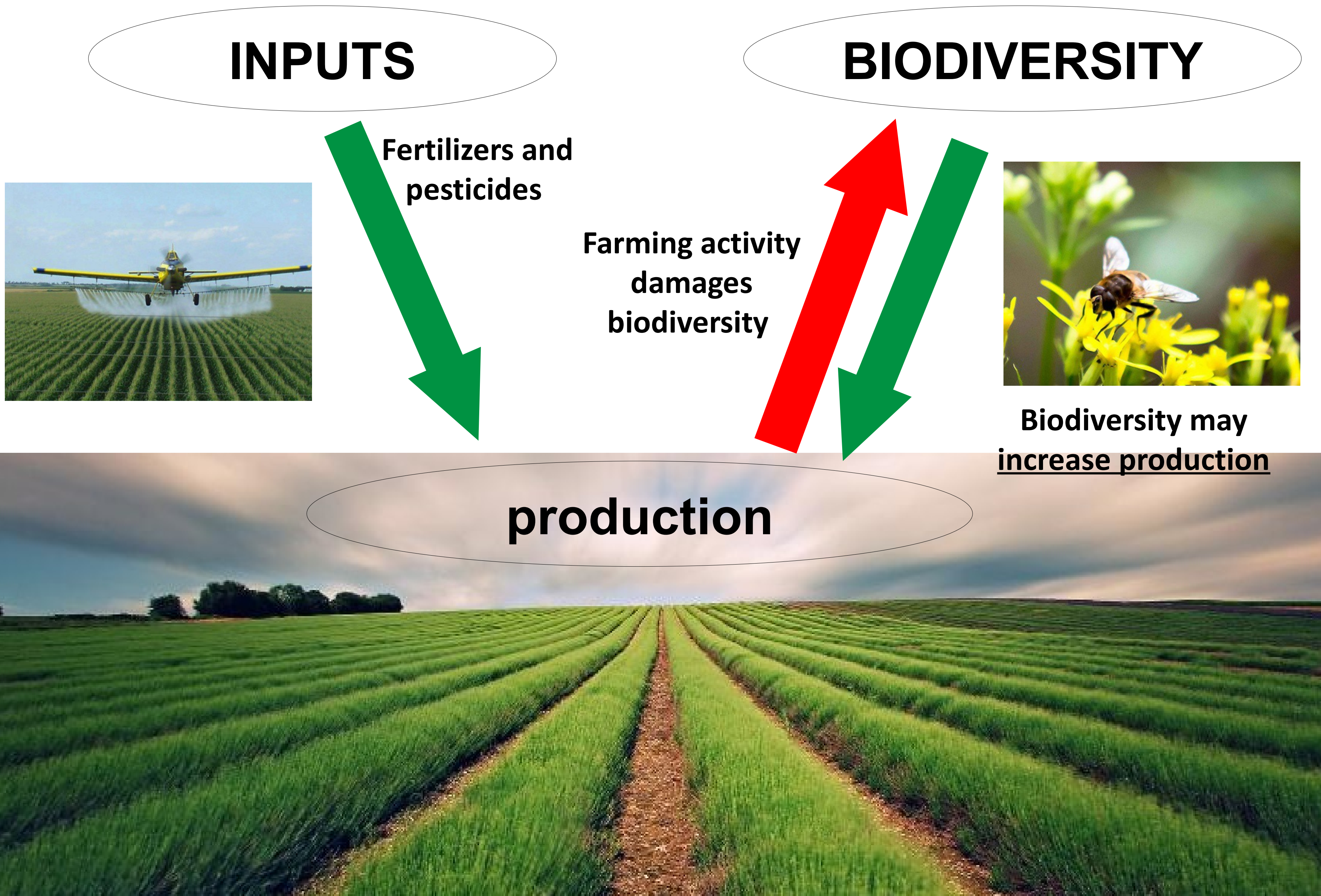
INPUTS

BIODIVERSITY

Fertilizers and pesticides

Farming activity damages biodiversity


INPUTS
BIODIVERSITY
Fertilizers and pesticides
Farming activity damages biodiversity
Biodiversity may increase production
production

Biodiversity Dynamics

- We suppose that **biodiversity** evolves in time according to a dynamic process which depends on the intrinsic growth of biodiversity and on the **farming activity**.
- Inspired by, "*Bio economic modeling for a sustainable management of biodiversity in agricultural Lands*" by Mouysset et al., we define a **Beverton-Holt** kind of model, which is a discrete time analogue of the logistic equation.

$$B_{t+1} = \frac{RB_t}{1 + B_t/M_t} = \frac{RB_tM_t}{M_t + B_t}$$

- **R** is the **intrinsic growth** factor of biodiversity;
- **Mt** represents the ability of the environment to host biodiversity;
- **Kt:=(R-1)Mt** is the **carrying capacity** of the environment;
- We define **Mt** as a negative linear function of inputs and production:

$$M_t := M(A_t, Q_t) = a - (bA_t + Q_t)$$

At ∊[0,1] represents the amount of **inputs** used

Qt represents the **quantity** produced

Production function

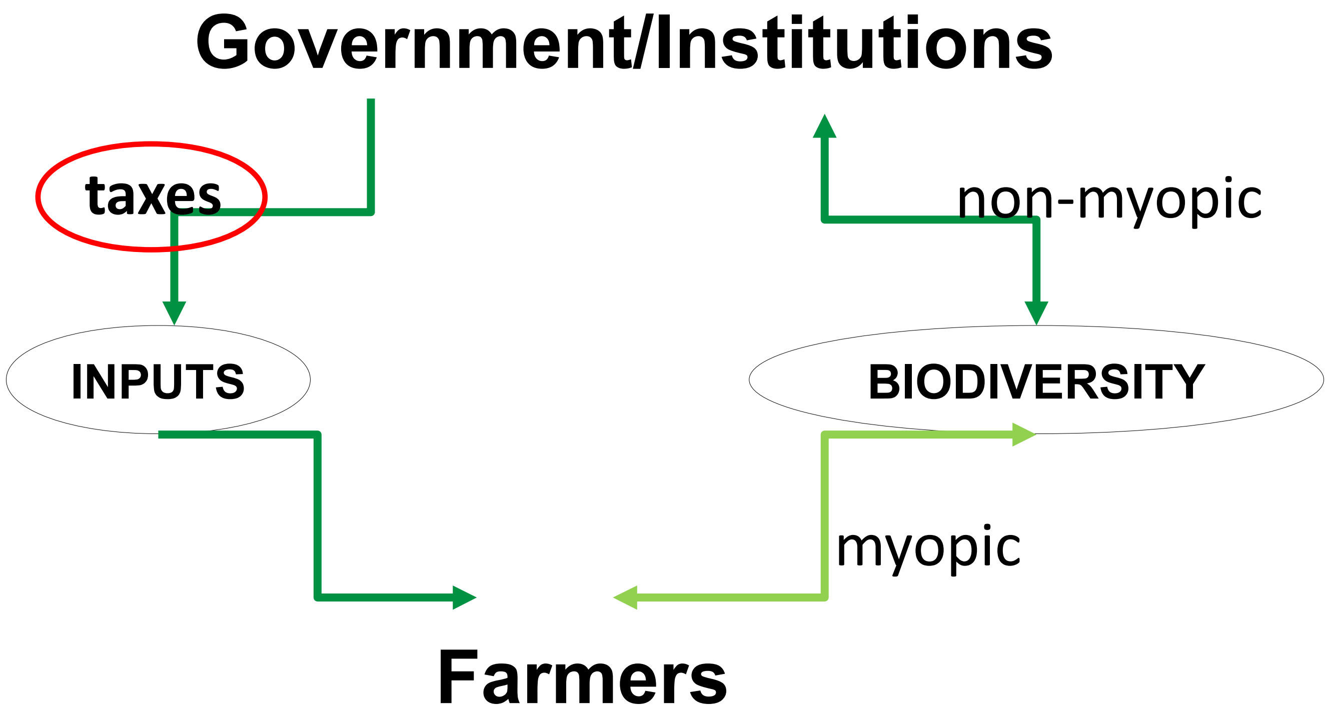
We define production as a **separable** function of At and Bt as follows:

biodiversity at time t

$$Q(A_t, B_t) := \alpha A_t + \beta B_t \; .$$

inputs used

The regulator is supposed consider biodiversity and he maximizes a certain utility function in order to determine the tax to impose



The farmer is supposed to maximize his own profit without considering biodiversity

The Farmer's Utility

Farmer's control

Tax on inputs

$$\mathcal{U}_t := pQ(A_t, B_t) - c(A_t) - \tau_t A_t + \sigma_t B_t$$

Fixed price

Cost

$$c(A) = \frac{c}{2}A^2$$

Subsidy to biodiversity

Farmer's optimal strategy

By maximizing farmer's utility,we obtain the optimal A*:

$$\frac{\partial \mathcal{U}}{\partial A} = \alpha p - cA - \tau = 0 \Rightarrow A^* = \frac{\alpha p - \tau}{c}$$

We determine the corresponding optimal Qt and Bt:

$$Q_t^* = Q(A^*) = \alpha \frac{\alpha p - \tau}{c} + \beta B_t$$

$$B_{t+1}^* = \frac{RB_t[a - (\alpha + b)A^* + \beta B_t]}{a - (\alpha + b)A^* + (1 + \beta)B_t}$$

Steady state (t→∞)

$$B^* = \frac{(R-1)[a - (\alpha + b)A^*]}{1 + (R-1)\beta}$$

NON Myopic regulator

We introduce a non-myopic regulator maximizing:

$$\max_{A_t, B_t} \sum_{t=0}^{\infty} \rho^t \left(p(\alpha A_t + \beta B_t) - c/2 A_t^2 \right)$$

Subject to:

$$B_{t+1} = \frac{R B_t [a - (\alpha + b) A_t + \beta B_t]}{a - (\alpha + b) A_t + (1 + \beta) B_t}$$

This **constrained optimization** problem can be solved as:

$$\max_{A_t, B_t} \sum_{t=0}^{\infty} \rho^t \left(p(\alpha A_t + \beta B_t) - c/2 A_t^2 + \lambda_{t+1} \left(\frac{R B_t [a - (\alpha + b) A_t + \beta B_t]}{a - (\alpha + b) A_t + (1 + \beta) B_t} - B_{t+1} \right) \right)$$

Lagrange multiplier

By imposing the first order conditions (i.e. derivatives wrt At and Bt=0) , we obtain the optimal solutions.

At the **steady state**

$$B^{op} = \frac{(R-1)[a-(\alpha+b)A^{op}]}{1+(R-1)\beta} \quad \lambda^{op} = \frac{\rho p \beta R}{(R-1)^2\rho\beta - \rho + R}$$

$$A^{op} = -\frac{p}{c}\frac{\alpha(\rho - R) + b(R-1)^2\rho\beta}{(R-1)^2\rho\beta - \rho + R}$$

By imposing that

Regulator's optimal solution → $A^{op} - A^* = 0$ ← Farmer's optimal solution

$$A^* = \frac{\alpha p - \tau}{c}$$

the regulator determines the **optimal tax**

Steady state (t->∞)

$$\tau^{\infty} = \frac{p\beta\rho(R-1)^2(\alpha+b)}{(R-1)^2\rho\beta - \rho + R}$$

An alternative method: a Stackelberg game

In **game theory**, is a two stages competition among two players, a **leader** – moving first - and a **follower**, each one maximizing its own utility function .

The game is solved by **backward induction**: one first compute the follower’s best response to a given leader’s action and then, one ca obtain the leader’s optimal strategy.

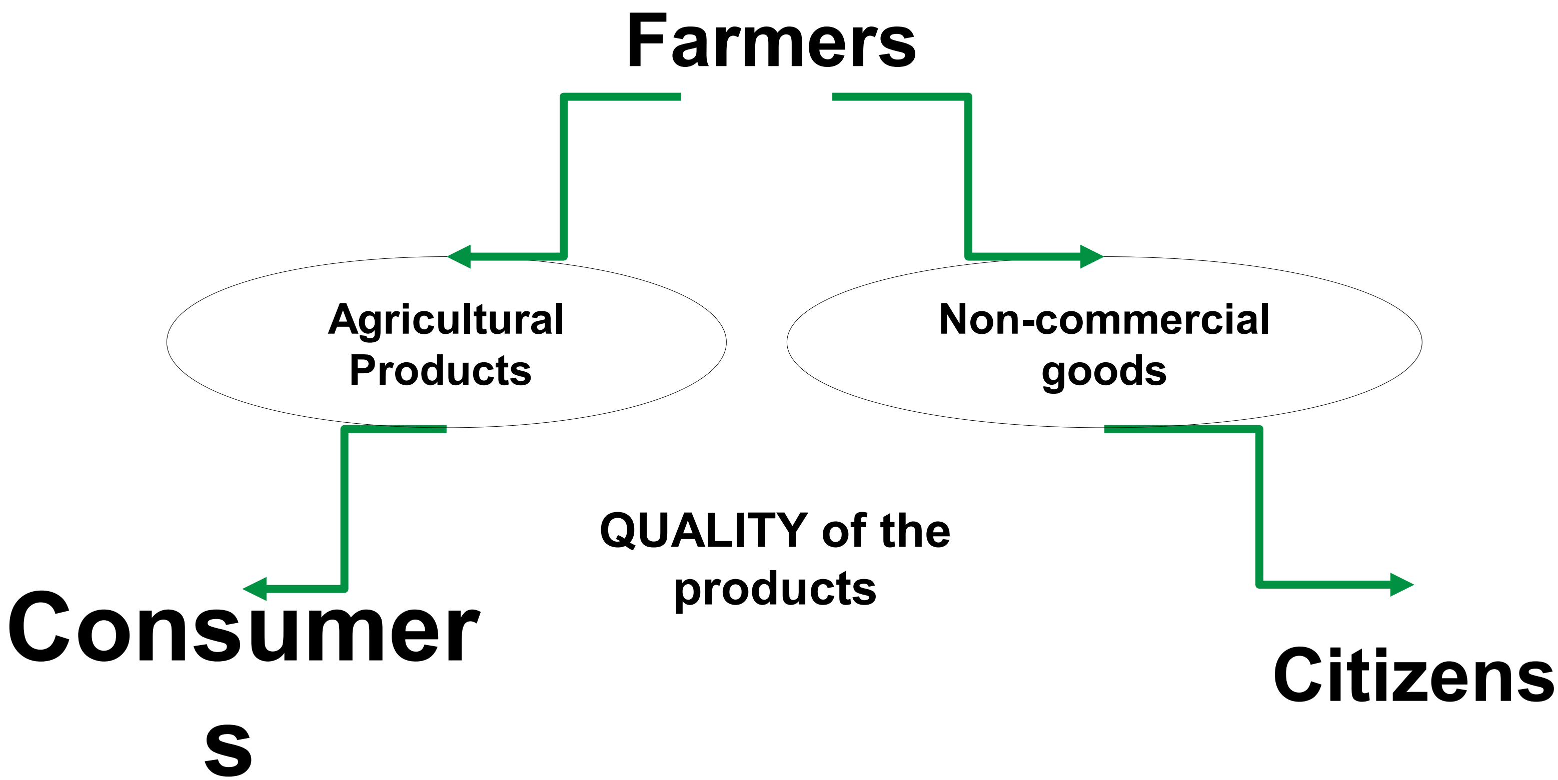
In our context:

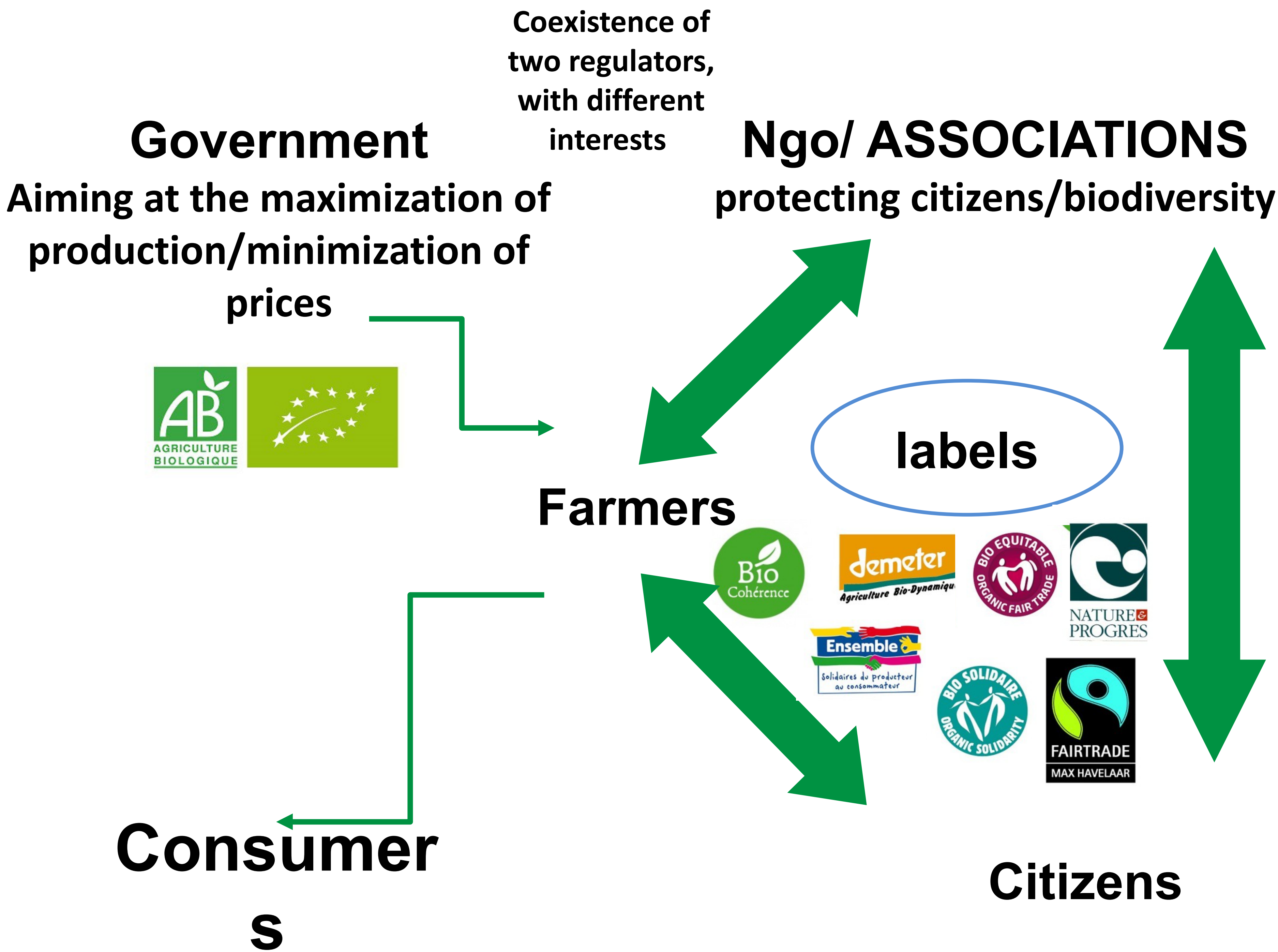
- The **regulator** is the **leader**;
- The **farmer** is the **follower**;
- The farmer's find his best strategy A* (given a fixed τ);
- Given A*, we the regulator maximizes his utility function, whose control is τ;
- The regulator obtains τ *, which is the best response to A* (second best). The equilibrium is thus given by the couple (A*, τ *)

Next seps

- Numerically solve the problem to obtain τt.
- Define a different utility for the regulator, who should not only consider the evolution of biodiversity, but aim at protecting it (define an amenity function for biodiversity).
- Consider a game between **two asymmetric farmers** and a regulator.

Future developments




Coexistence of two regulators, with different interests
Government
Aiming at the maximization of production/minimization of prices
AB
AGRICULTURE BIOLOGIQUE
Ngo/ ASSOCIATIONS
protecting citizens/biodiversity
labels
Farmers
Bio Cohérence
demeter
Agriculture Bio-Dynamique
BIO EQUITABLE
ORGANIC FAIR TRADE
NATURE & PROGRES
Ensemble
Solidaires du producteur au consommateur
BIO SOLIDAIRE
ORGANIC SOLIDARITY
FAIRTRADE
MAX HAVELAAR
Consumer
s
Citizens


Thank you for your attention!
Questions and remarks are welcome!