Finanziato dall'Unione europea NextGenerationEU | Ministero dell'Università e della Ricerca | Italiadomani | Università degli studi "G. d'Annunzio" | Consiglio Nazionale delle Ricerche | crea

ECOWHEATALY

Evaluation of policies for enhancing sustainable wheat production in Italy

PRIN MUR 2022

Task 2.2

Modeling the Italian wheat system

Gianfranco Giulioni

Missione 4 Istruzione e Ricerca

Current state of the ABM

Presently, the ABM

- create agents: Farms and Policy maker (?)
- perform the first farms' decision on production inputs
- can run on several core at the same time (parallel execution)

Next slide shows the output to screen of a run with two farms for each rank and a policy maker.

(?) to be discussed.

Screen output

```
RANK 0
Random seed 570285
======= begin create agents ======
Adding Policy Maker to rank 0
hello from Policy Maker 0 I am in rank 0
(0, 1, 0)
hello from farm 0 I am in rank 0
hello from farm 1 I am in rank 0
======= End create agents ======

hello, I am going to start the simulation
farm 0 I am in rank 0 inputs decision:
  Nitrogen = 106.05
  herbicide = 2.32
  insecticide = 0.97
  my target yield is 36.41
  expected sale revenue 1092.0 costs 187
  expected profit 905
farm 1 I am in rank 0 inputs decision:
  Nitrogen = 108.12
  herbicide = 1.75
  insecticide = 0.13
  my target yield is 35.21
  expected sale revenue 1056.0 costs 177
  expected profit 879
simulation performed!
```

```
RANK 1
Random seed 489191
======= begin create agents ======
hello from farm 0 I am in rank 1
hello from farm 1 I am in rank 1
hello from Policy Maker 0 I am in rank 0


======= End create agents ======

hello, I am going to start the simulation
farm 0 I am in rank 1 inputs decision:
  Nitrogen = 95.63
  herbicide = 1.27
  insecticide = 0
  my target yield is 34.31
  expected sale revenue 1029.0 costs 154
  expected profit 876
  farm 1 I am in rank 1 inputs decision:
  Nitrogen = 108.51
  herbicide = 1.47
  insecticide = 0.18
  my target yield is 35.28
  expected sale revenue 1058.0 costs 176
  expected profit 882
simulation performed!
```

Outline

Below we will enter into details of:

- Modeling farm decision
- Modeling the wheat system
  - farm heterogeneity
  - differences in production conditions

Farm decision

Usual economic problem: profit maximization

$$\pi = p_w y(x_1, x_2, ...) - \sum_i p_{x_i} x_i$$

where

- π profit per hectare
- p_w wheat price
- y yield per hectare
- x_i input i per hectare
- p_{x_i} input i price

Yield model

i also indexes stress factors:

- $i = 1$ plant nutrition
- $i = 2$ weeds
- $i = 3$ insects, ...

Assumption: each production input relieves only 1 stress.
Economics: inputs are not substitutes (they are perfect complements). (?)

It is not possible to obtain the same yield by increasing one input and decreasing another.

Complement inputs

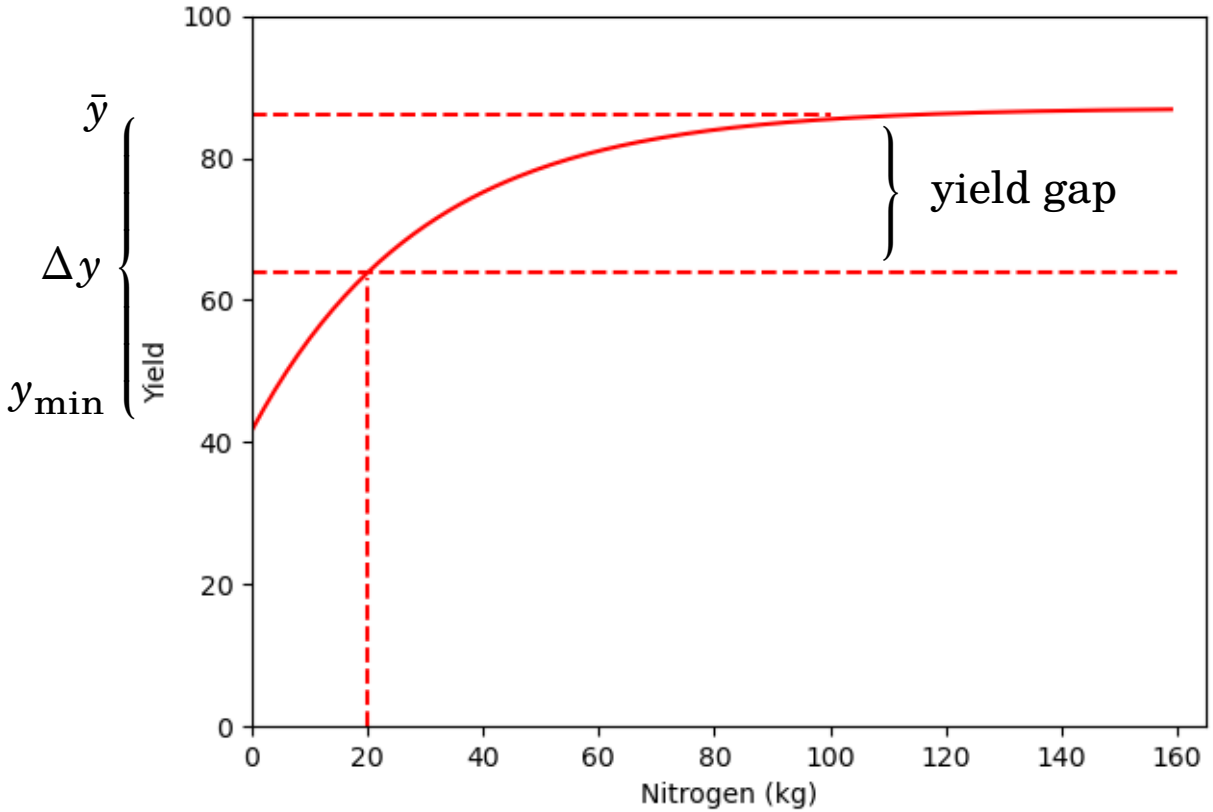
Under the "complement inputs" condition we define the **conditional yield**:

> yield obtained if only stress factor i is binding

$$y_i(x_i) = \underbrace{\bar{y}(1 - s_i)}_{x_i = 0} + \underbrace{\bar{y} s_i (1 - e^{-\lambda_i x_i})}_{\text{gain using } x_i}$$

where s_i is the share of production lost if the farm do not fight the stress factor.

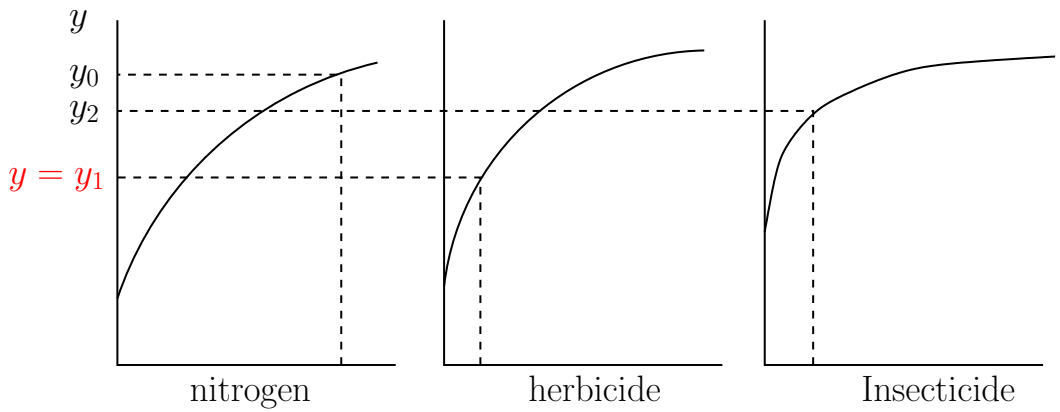
Conditional y of nitrogen



Yield

Under the "complement input" assumption the yield is equal to the conditional yield of the most binding stress factor:

$$y = \min(y_i)$$

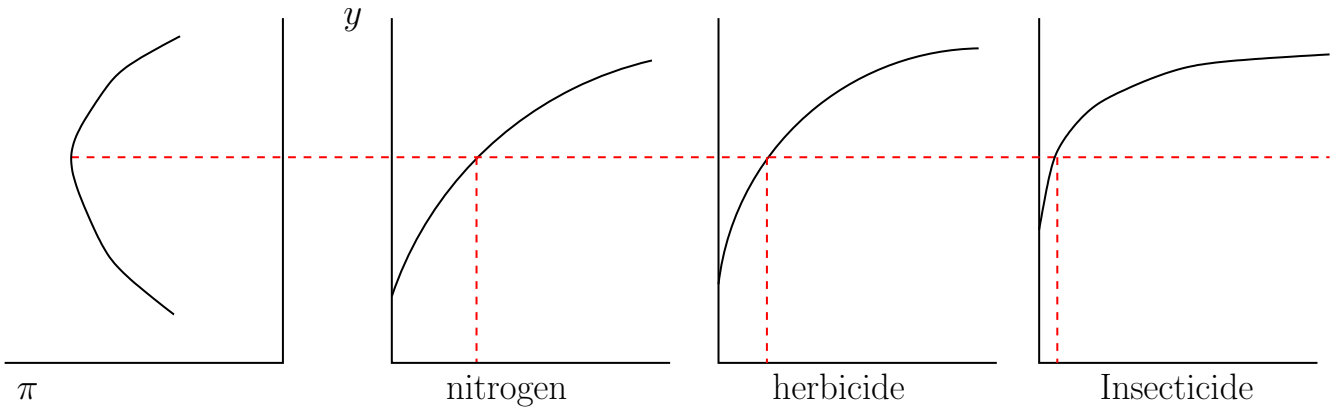


Profit

Profit function becomes

$$\pi = p_w \min(y_i) - \sum_i p_{x_i} x_i$$

Its Maximization delivers the target yield $\hat{y}^*$ that allows finding the inputs quantities needed to achieve it: $\hat{x}_1^*$, $\hat{x}_2^*$, ...



Profit maximization

Solution strategy:

- find x_i that satisfy $y_i = \hat{y}$. Denote it $\hat{x}_i$. $\hat{x}_i$ depends on $\hat{y}$
- because $y_i = \hat{y}$ for all i, $\min(y_i) = \hat{y}$
- substituting, the profit function depends on $\hat{y}$ only
- maximize profit with respect to $\hat{y}$ to obtain the target yield $\hat{y}^*$
- $\hat{y}^*$ is used to identify the optimal inputs mix: $\hat{x}_1^*$, $\hat{x}_2^*$, $\hat{x}_3^*$, ... using the results in the first bullet.

Examples

Model inputs:

$p_w = 300$ per ton
$\bar{y} = 5$ ton/ha

i	stress factor	s	$\bar{s}$	p_x	λ	x
0	Lack of Nitrogen	0.5	0.5	1.5	0.005	supply of N (kg)
1	weeds	0.4	0.4	8	0.2	herbicide (kg)
2	Insects	0.3	0.3	5	0.1	Insecticide (kg)

Model outputs:

$\hat{y}^* = 3.7$
$\hat{x}_0^* = 130.79$, $\hat{x}_1^* = 2.15$, $\hat{x}_2^* = 1.43$
$\pi^* = 889$

yield gap $= \bar{y} - \hat{y}^* = 1.3$

A shock

New more damaging and resistant insect

$$y_i(x_i) = \underbrace{\bar{y}(1-s_i)}_{x_i=0} + \underbrace{\bar{y}\bar{s}_i(1-e^{-\lambda_i x_i})}_{\text{gain using } x_i}$$

s_2 from 0.3 to 0.5

$\bar{s}_2$ from 0.3 to 0.1

i	stress factor	s	$\bar{s}$	p_x	λ	x
0	Lack of Nitrogen	0.5	0.5	1.5	0.005	supply of N (kg)
1	weeds	0.4	0.4	8	0.2	herbicide (kg)
2	Insects	0.5	0.1	5	0.1	Insecticide (kg)

Solution comparison

	$\hat{x}_1$	$\hat{x}_2$	$\hat{x}_3$	$\hat{y}$	π
benchmark	130.79	2.15	1.43	3.7	889
new insect	17.08	0	5.27	2.7	759

A policy

$p_w = 300$ per ton

$\bar{y} = 5$ ton/ha

i	stress factor	s	$\bar{s}$	p_x	λ	x
0	Lack of Nitrogen	0.5	0.5	1.5	0.005	supply of N (kg)
1	weeds	0.4	0.4	8	0.2	herbicide (kg)
2	Insects	0.3	0.3	5	0.1	Insecticide (kg)

Increasing the price of insecticides

p_{x_3}	$\hat{x}_1$	$\hat{x}_2$	$\hat{x}_3$	$\hat{y}$	π
5	130.79	2.15	1.43	3.7	889
7.5	118.36	1.84	0.81	3.62	887
10	106.66	1.55	0.22	3.53	885
≥ 11	102.17	1.44	0	3.5	885

Estimation

$$y_i = \underbrace{y_{\min}}_{\bar{y}(1-s_i)} + \underbrace{\Delta y_i}_{\bar{y}s_i}(1 - e^{-\lambda_i x_i})$$

we use data to estimate the parameters:

- Take the data of a set of farms
- Identify the convex hull
- Select points in the north-west portion of convex hull (NWCH)
- $y_{\min}$ is the minimum y of the NWCH

Estimation: $\hat{\Delta y_i}$ and $\hat{\lambda}_i$

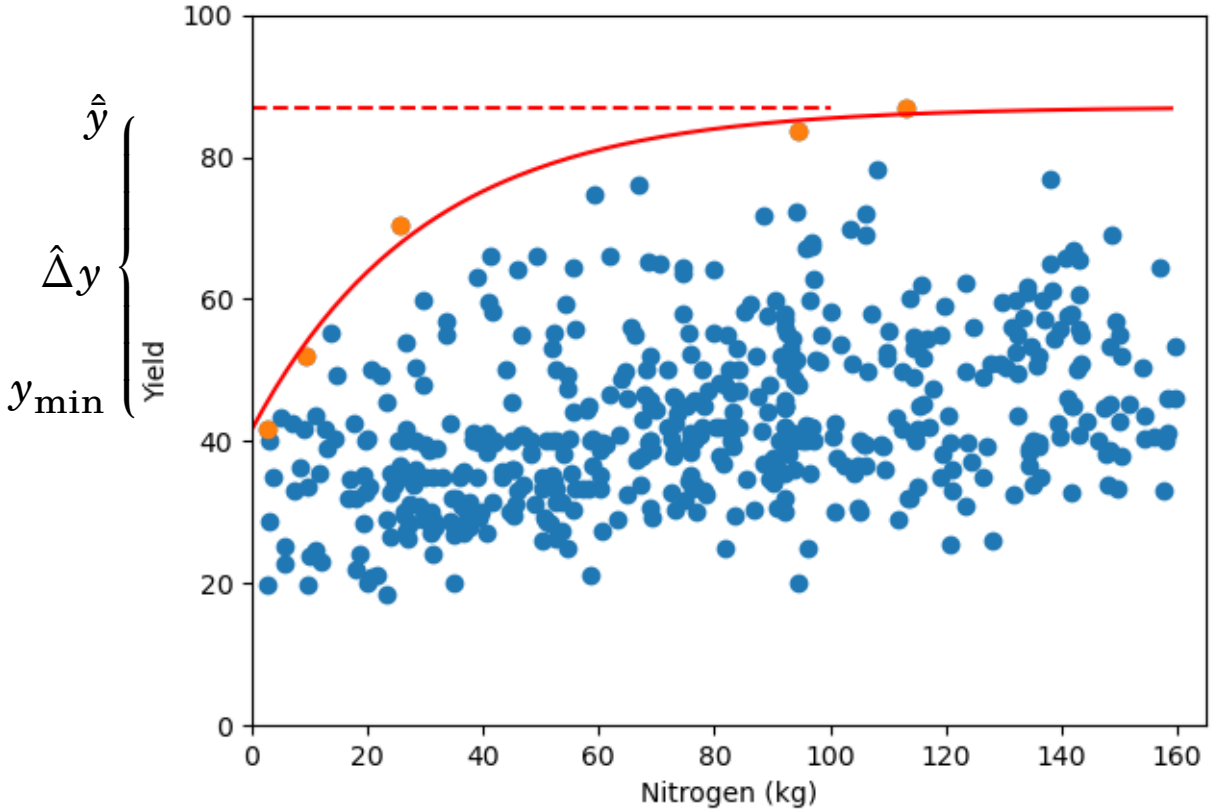
$$\underbrace{\tilde{y}_i}_{y_i - y_{\min}} = \Delta y_i (1 - e^{-\lambda_i x_i})$$

- j vertex of the NWCH set
- $\tilde{y}_i^j$ from data
- $\hat{y}_i^j = \Delta y_i (1 - e^{-\lambda_i x_i^j})$ from model

$$\min_{\Delta y_i, \lambda_i} \sum_j (\tilde{y}_i^j - \hat{y}_i^j)^2$$

gives estimates $\hat{\Delta y_i}$ and $\hat{\lambda}_i$

Visual representation



Estimation: $\bar{y}$ and s_i

Above we defined

$$\Delta y_i = \bar{y} s_i$$

with $\hat{\Delta} y_i$ we can also estimate $\bar{y}$:

$$\hat{\bar{y}} = y_{\min} + \hat{\Delta} y_i$$

Substituting estimations we have

$$\hat{\Delta} y_i = \hat{\bar{y}} s_i$$

and finally we obtain the estimation of s_i:

$$\hat{s}_i = \frac{\hat{\Delta} y_i}{y_{\min} + \hat{\Delta} y_i}$$

System model

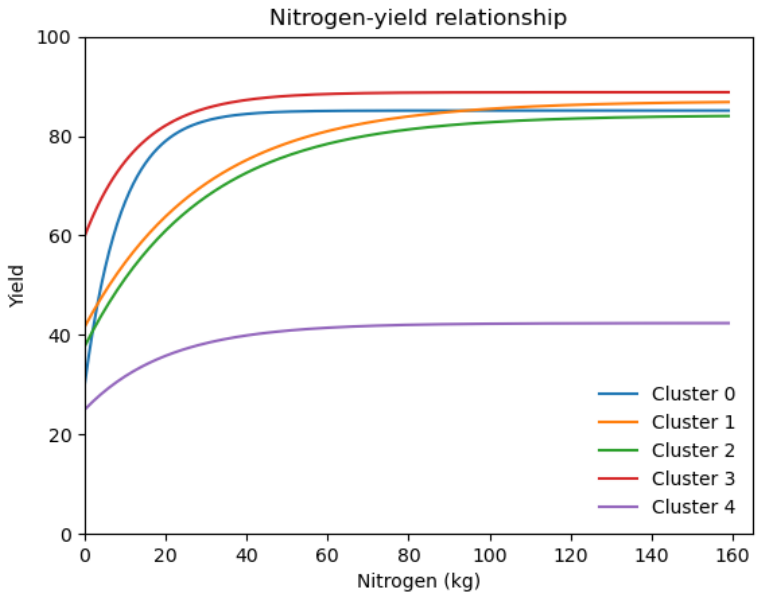
Modeling the whole system require accounting for

- Heterogeneity in farm behavior
- Differences in production conditions
  - local climate
  - land quality
  - irrigation, ...

Farm heterogeneity

- Implement a cluster analysis to identify types of farms in the dataset
- Identify the parameters characterizing each cluster

Clusters parameters



cluster	$y_{\min}$	$\hat{\bar{y}}$	$\hat{s}$	$\hat{\lambda}$
0	30.13	85.12	0.646	0.1099
1	19.79	84.81	0.767	0.0665
2	37.74	84.21	0.552	0.0347
3	59.92	88.80	0.325	0.0733
4	25.00	42.39	0.410	0.0487

Farms heterogeneity

Given differences in clusters, the challenge is how differentiate farms inside clusters.

In terms of yield, for example, the idea is to implement the sequence

$$\hat{y}_i^* \rightarrow \hat{y}_{i,z}^* \rightarrow y_{i,z}$$

where
$\hat{y}_i^*$ cluster i target yield
$\hat{y}_{i,z}^*$ farm $z \in$ cluster i target yield
$y_{i,z}$ farm $z \in$ cluster i obtained yield

Heterogeneity within a cluster ⑦

$$\hat{y}_i^* \rightarrow \hat{y}_{i,z}^* \rightarrow y_{i,z}$$

- Allows for **random shift of farms parameters** from reference group averages ($y_{\min}$, $\bar{y}$ and λ) (λ shifts shown in the screen output slide).
- Allows for **non profit maximizer farms**.
- Allows **sampling**:
  - For each cluster, study the statistical distribution of the variables needed to initialize the agent-based model.
  - increase the number of farms in the system creating **artificial farms** whose initial conditions are draw from distributions found in the previous step.

How to include other farm specific conditions ?

How to account for other factors such as local climate change, land quality, ittigation?

$$\hat{y}_i^* \rightarrow \hat{y}_{i,z}^* \rightarrow y_{i,z}$$

- Add random shock to yield taking account of the yield dispersion of the cluster?
- What else?

To discuss

- are there other agents affecting farm decisions?
- Is the "complement input" assumption a good approximation of reality?
- how to introduce heterogeneity within a cluster?
  - parameters random shifts
  - non-maximizer agents
  - artificial agents
- how to include other farm specific conditions?

THE END