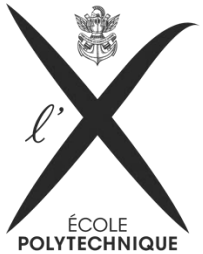
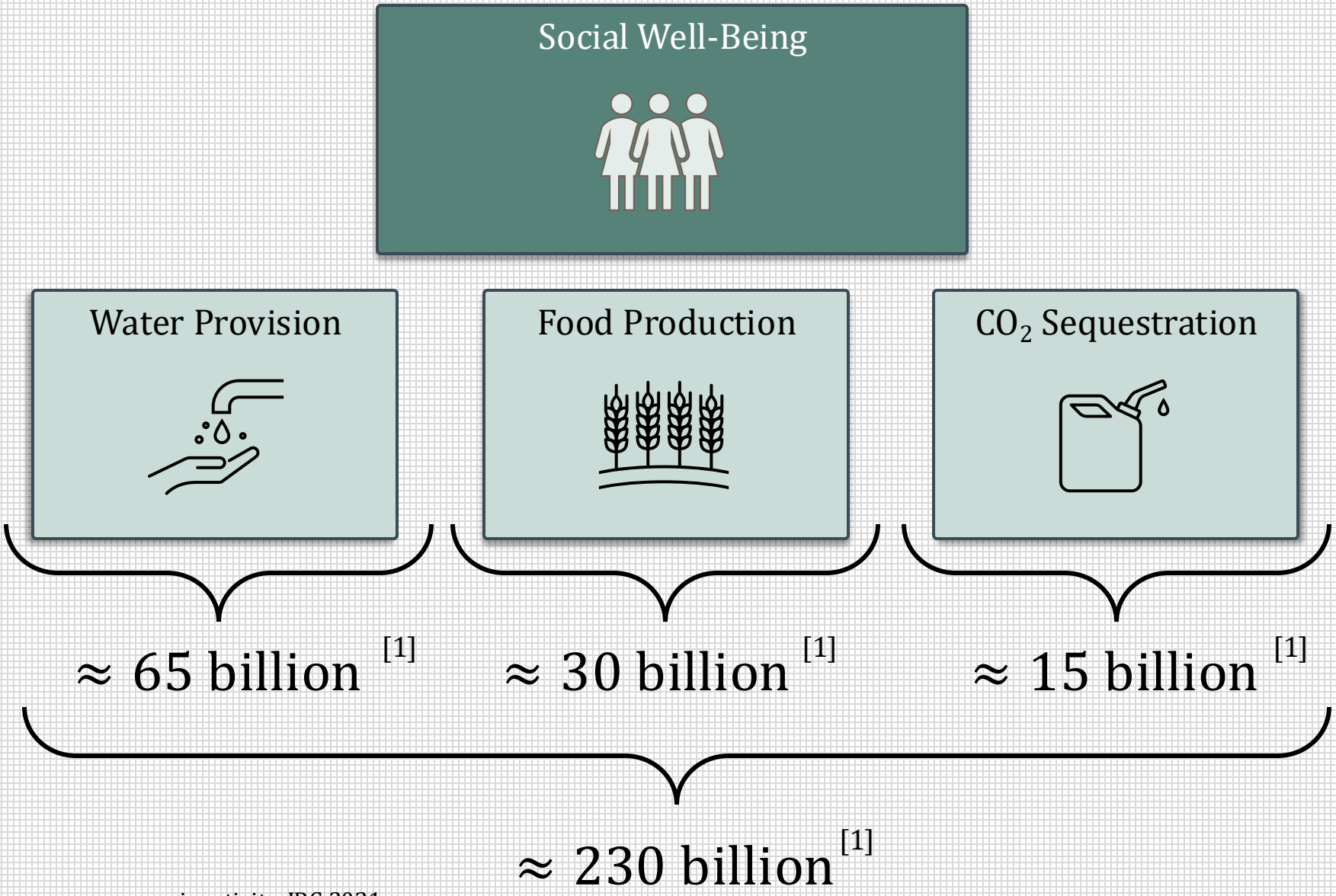
Mitigating Farmland Biodiversity Loss: A Bio-Economic Model of Land Consolidation and Pesticide Use

Elia Moretti & Michael Benzaquen

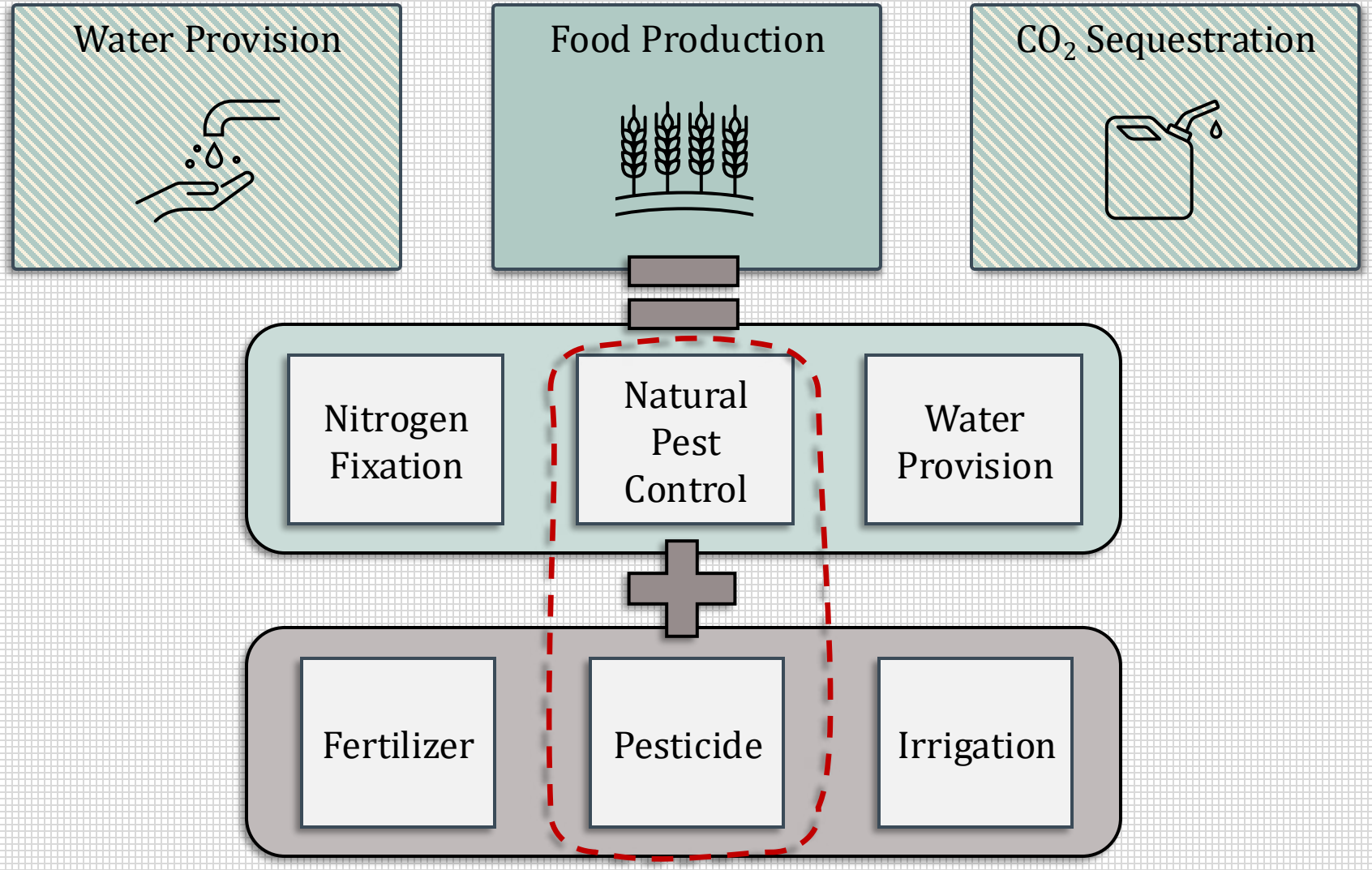


The role of ecosystem services



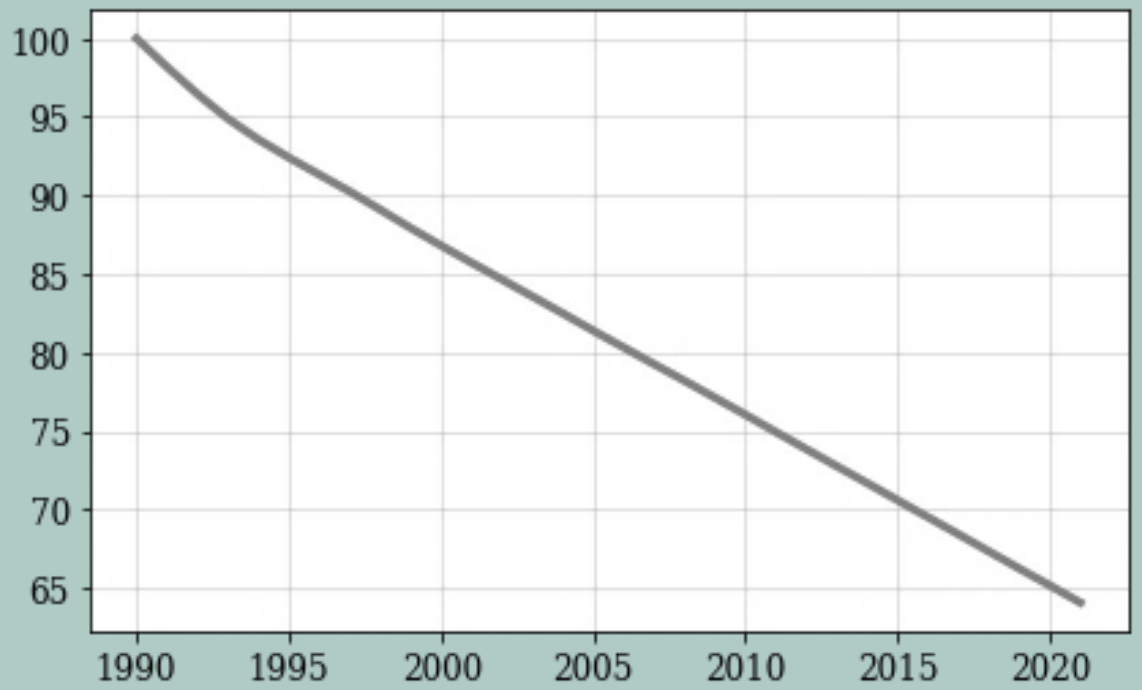
[1] Accounting for nature in euro area economic activity, JRC 2021

The role of ecosystem services

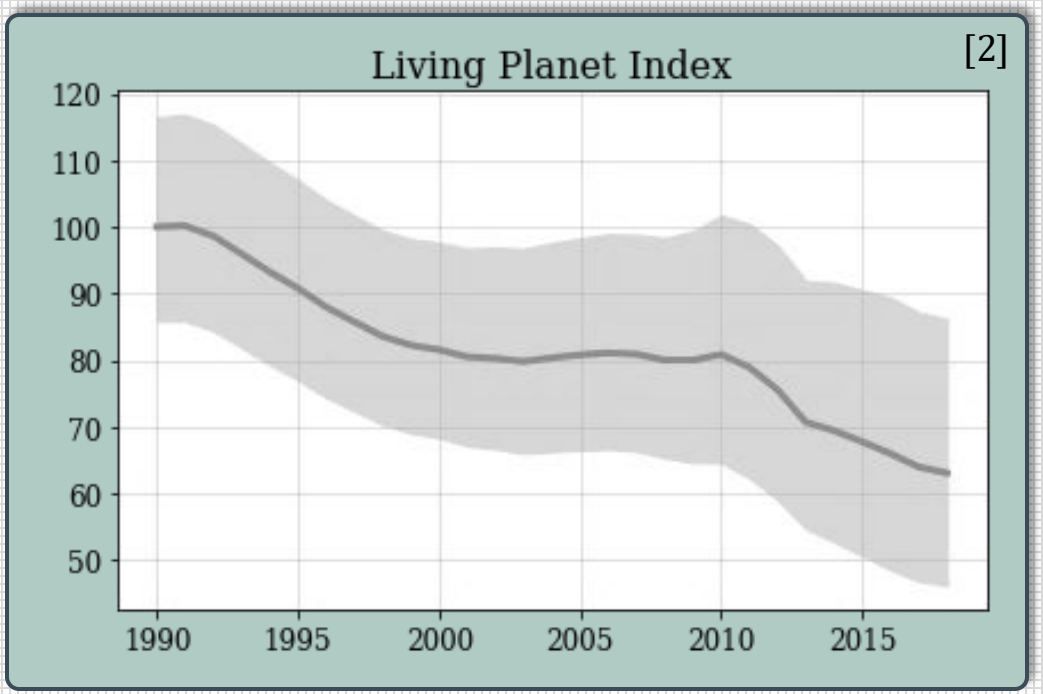


Biodiversity has been declining

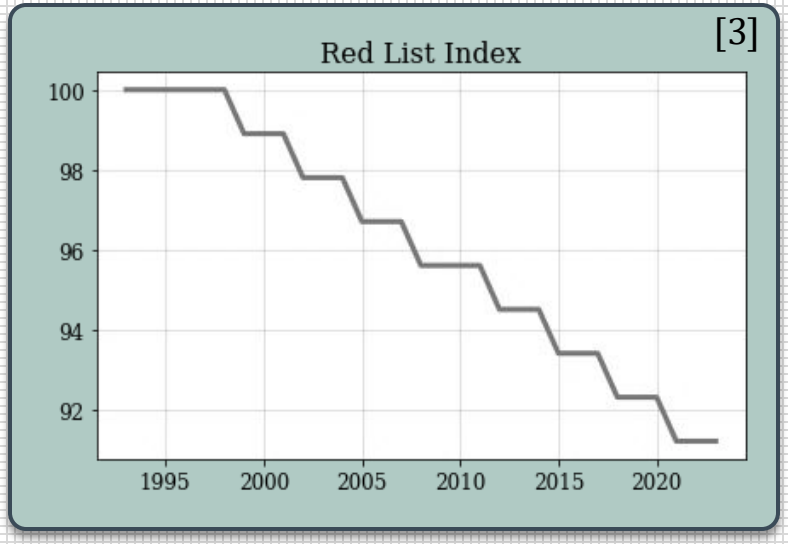
[1]



[2]



[3]

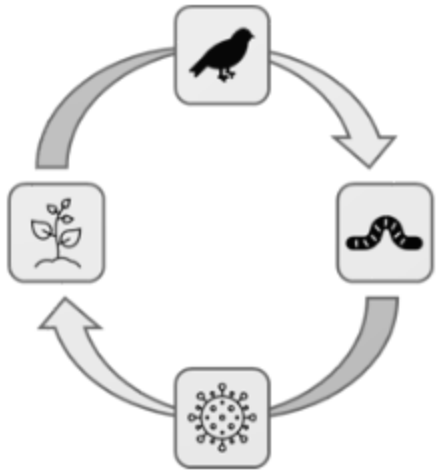


[1] Common bird index by type of species - EU aggregate (source: EBCC), European Bird Census Council (EBCC)
[2] World Wildlife Fund (WWF) and Zoological Society of London
[3] Birdlife International and International Union for Conservation of Nature

Who is the responsible? The agricultural sector

Agri-Land: ≈ 30%

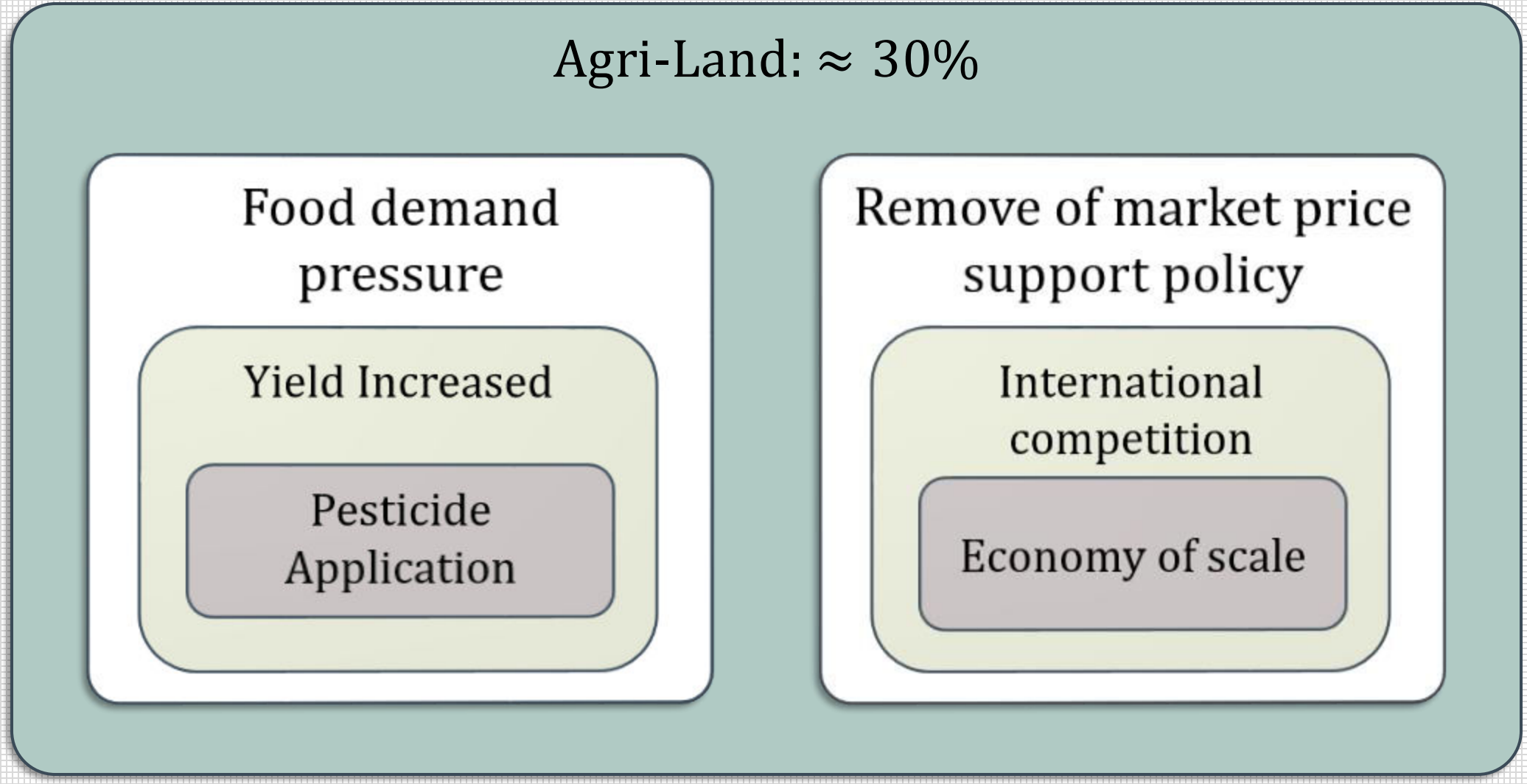
Pesticide Application: ≈ 2 Kg/ha



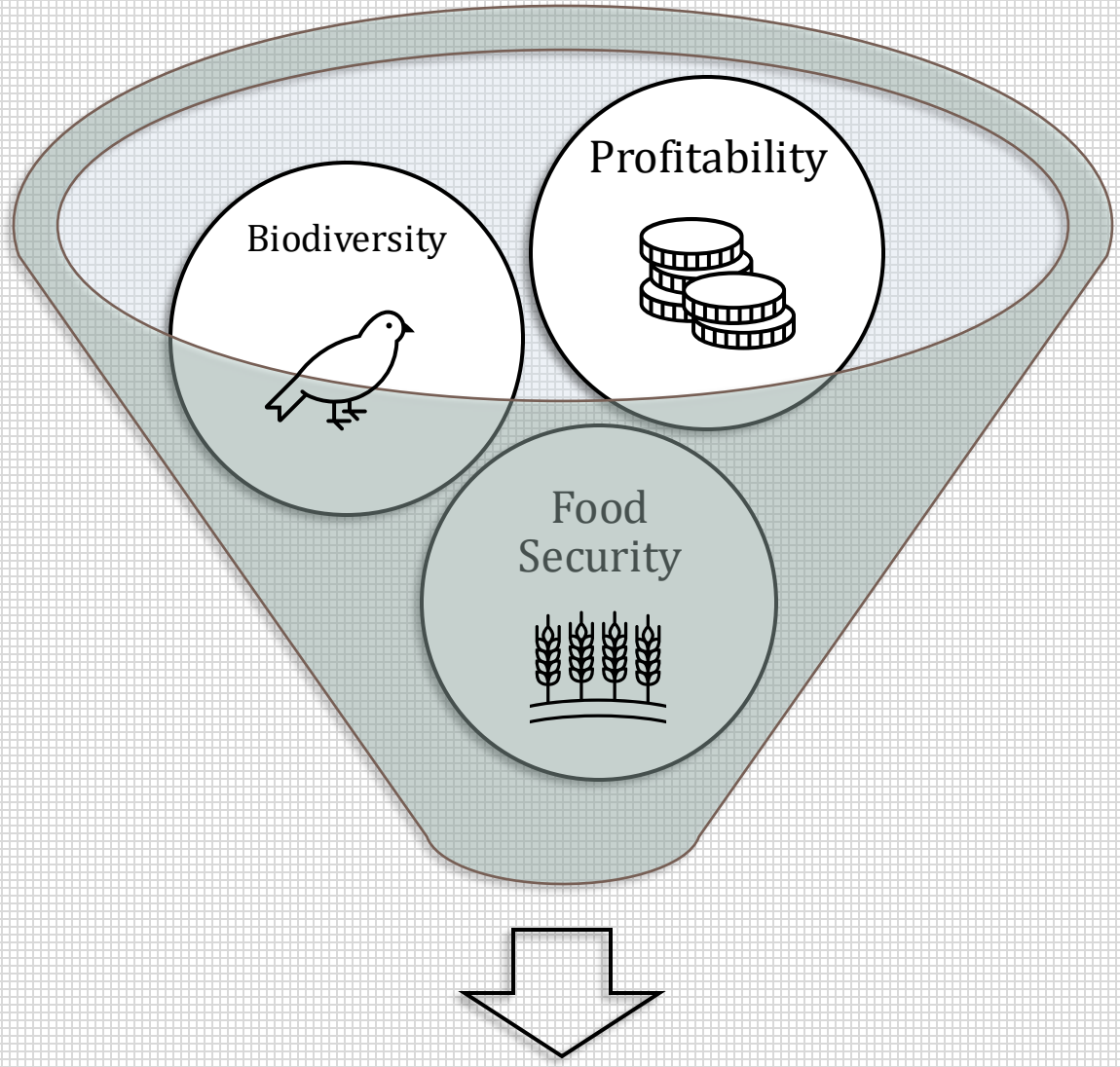
Land Consolidation

Average Farm Size: ≈ 100 ha

Who is the responsible? The agricultural sector



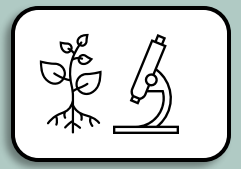
The Problem

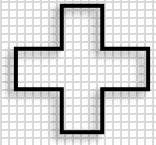


Long-term prosperity

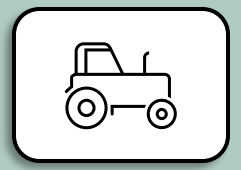
The Existing Literature

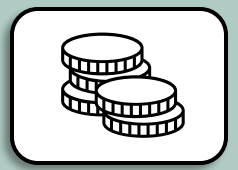
Ecological Models



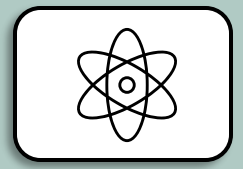


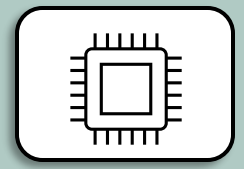
Economic Models



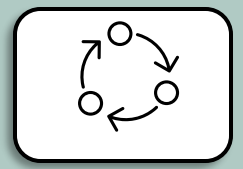


Large Models

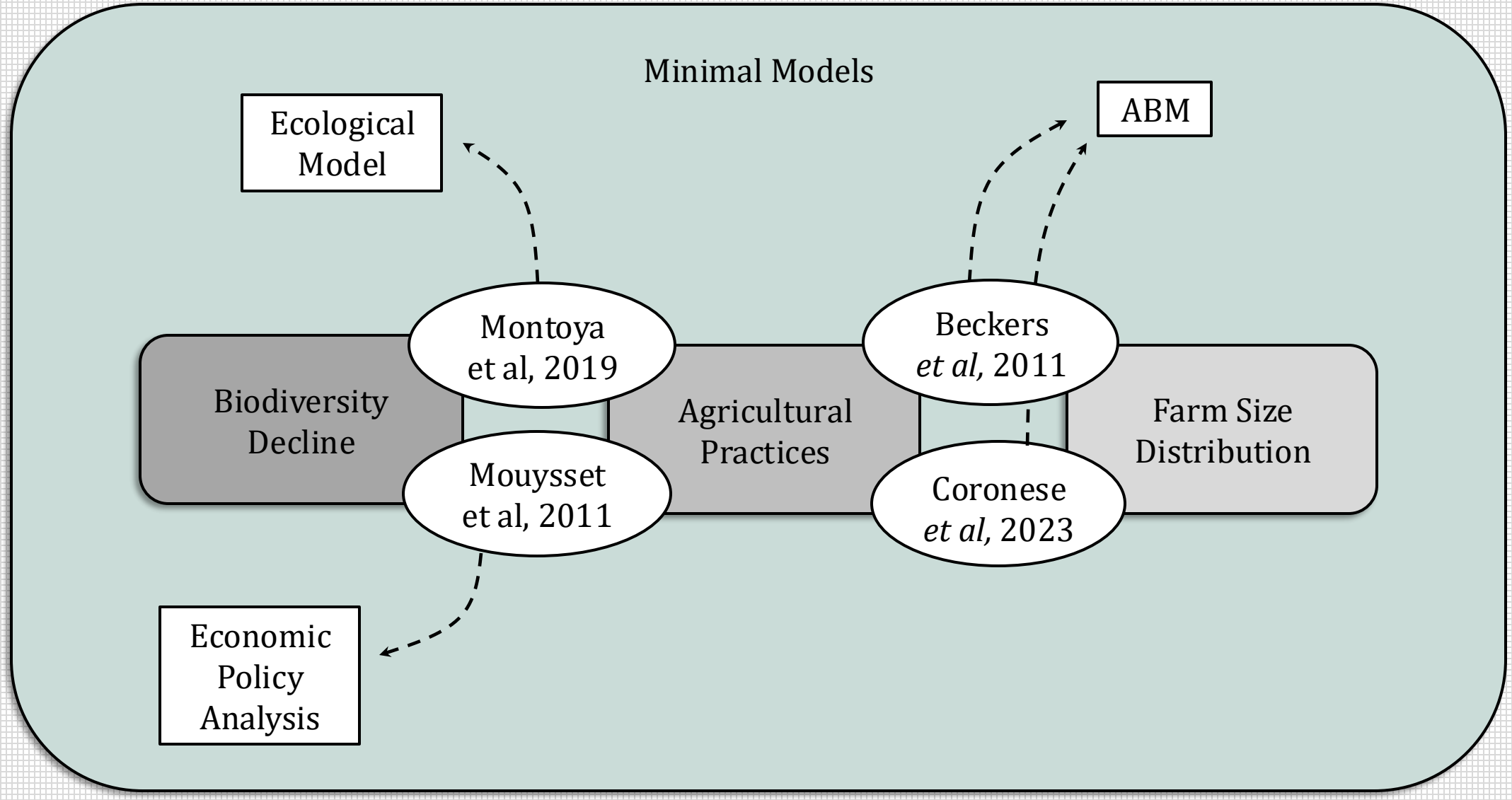




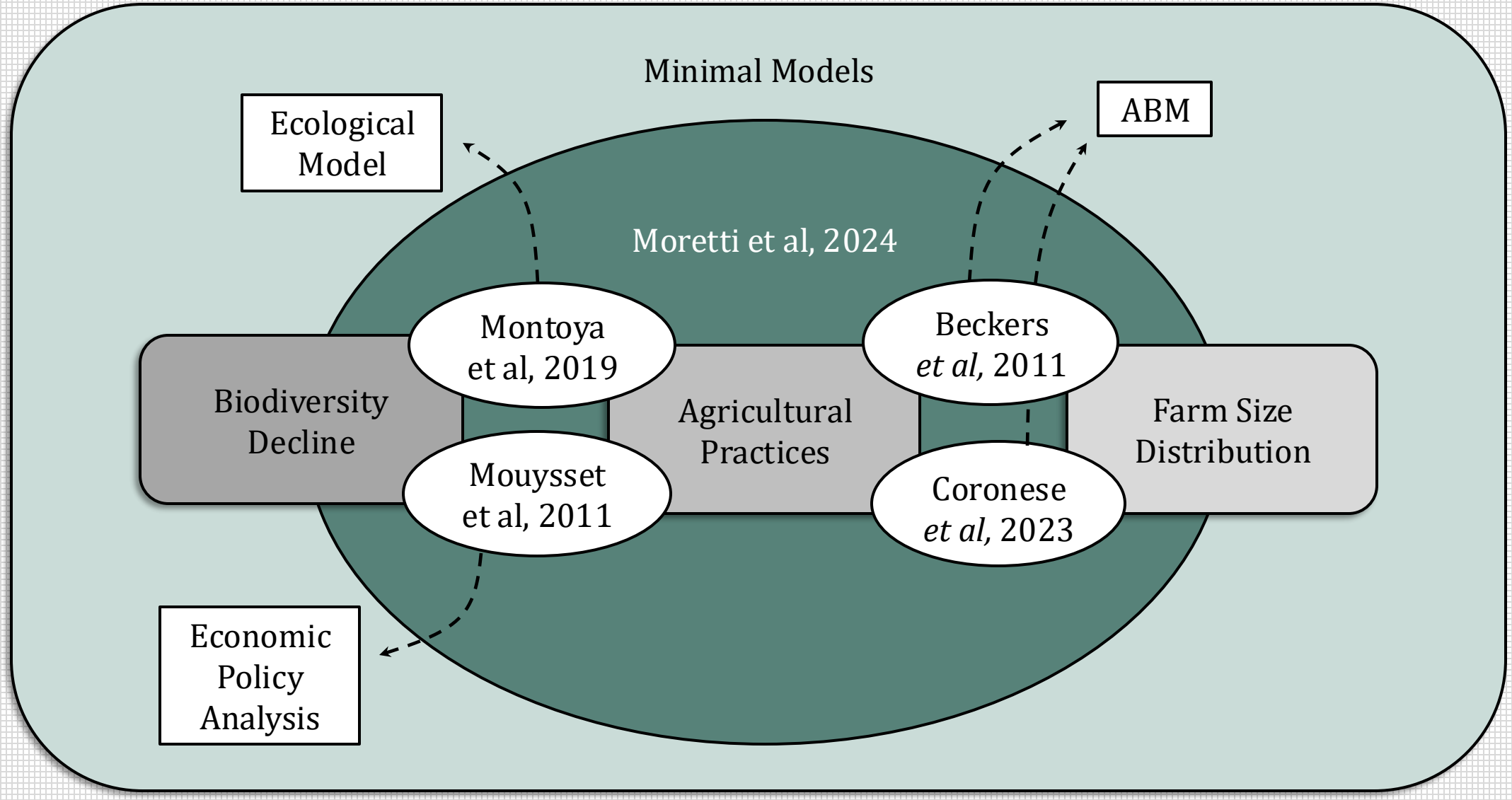
Minimal Models



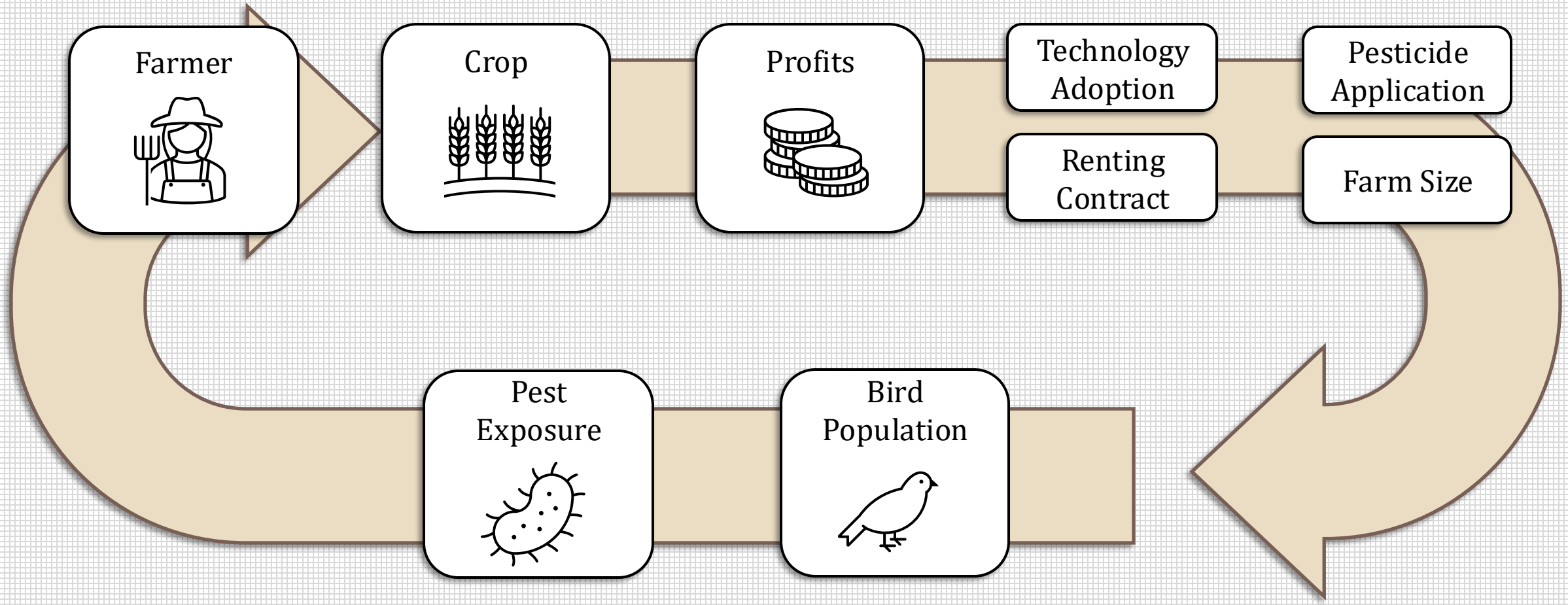
The Existing Literature



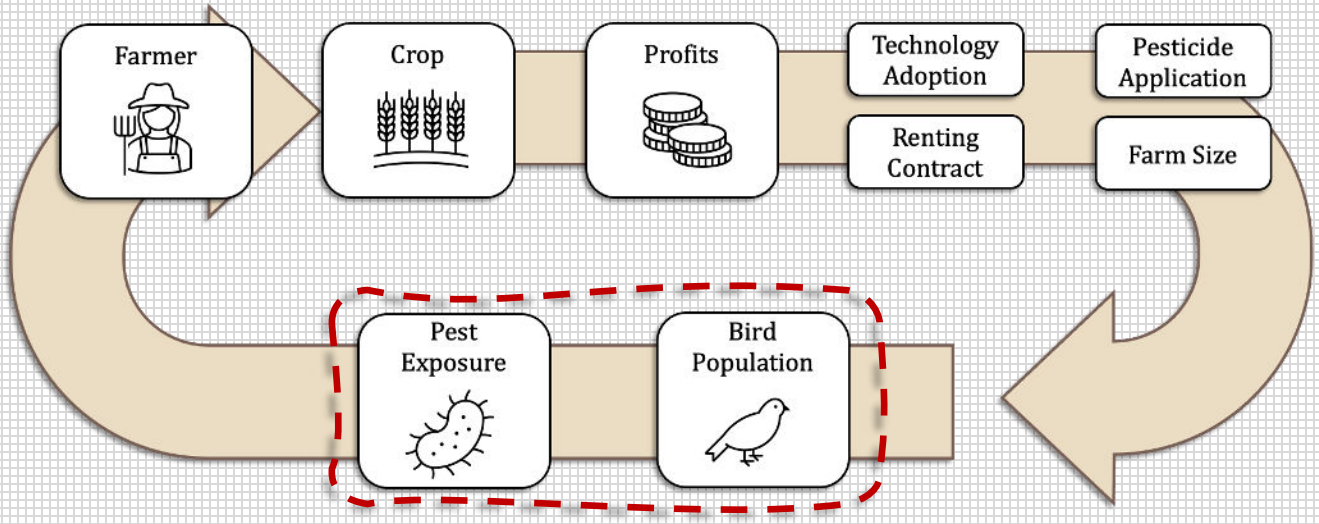
The Existing Literature



Outlooks


Farmer
Crop
Profits
Technology Adoption
Renting Contract
Pesticide Application
Farm Size
Bird Population
Pest Exposure

Outlooks



Ecological Model

$$\dot{\varepsilon}_t = r_\varepsilon \left(1 - \frac{\varepsilon_t}{K_t}\right) \varepsilon_t$$

$$K_t = \mu \frac{\bar{L}_0}{\bar{L}_t} + (1-\mu) \frac{\bar{P}_0}{\bar{P}_t}$$

$$\pi_t = \pi_0 \left(\frac{\varepsilon_0}{\varepsilon_t}\right)^a$$

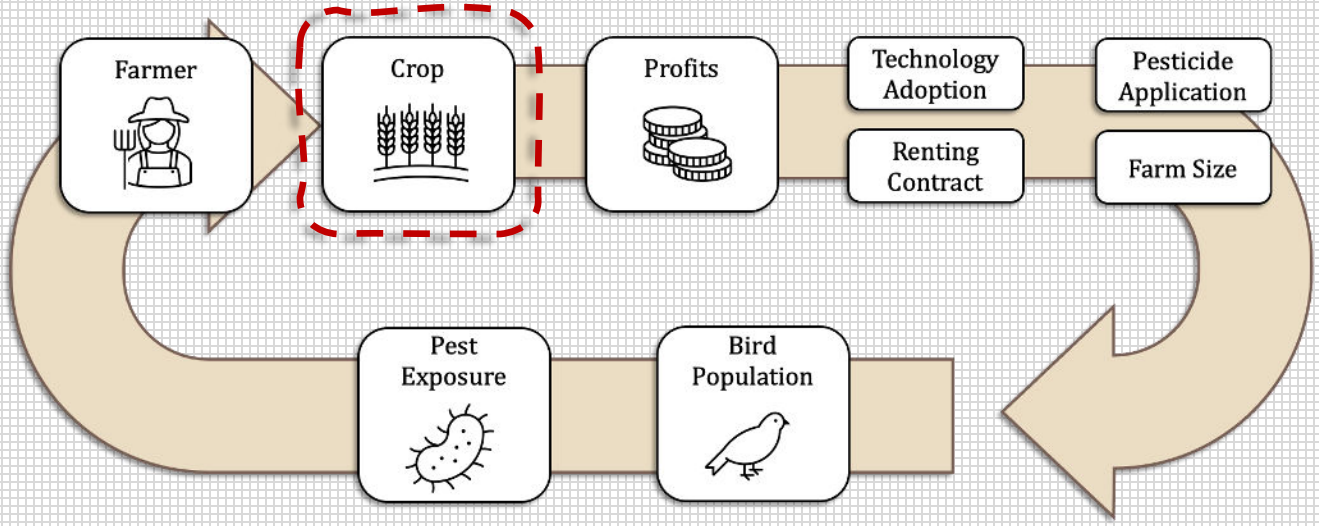
Biodiversity

Average Farm Size

Pest Exposure

Average Pesticide Use per Ha

Outlooks



Efficiency

Goods Production

$$y_{i,t} = y_{\max}\left[1 - \pi_t \exp\left(-\frac{e_{i,t}P_{i,t}}{P_{\text{ref}}}\right)\right](1+\xi_{i,t})$$

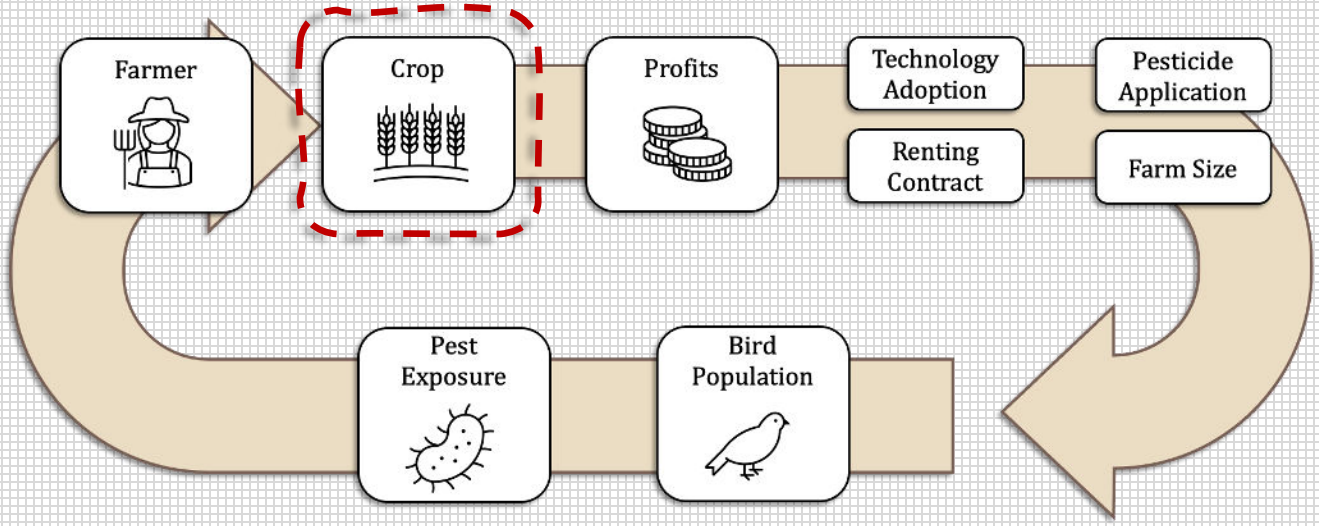
$$Y_{i,t} = L_{i,t}y_{i,t}$$

Pest Exposure

Farm Size in Ha

Pesticide Use per Ha

Outlooks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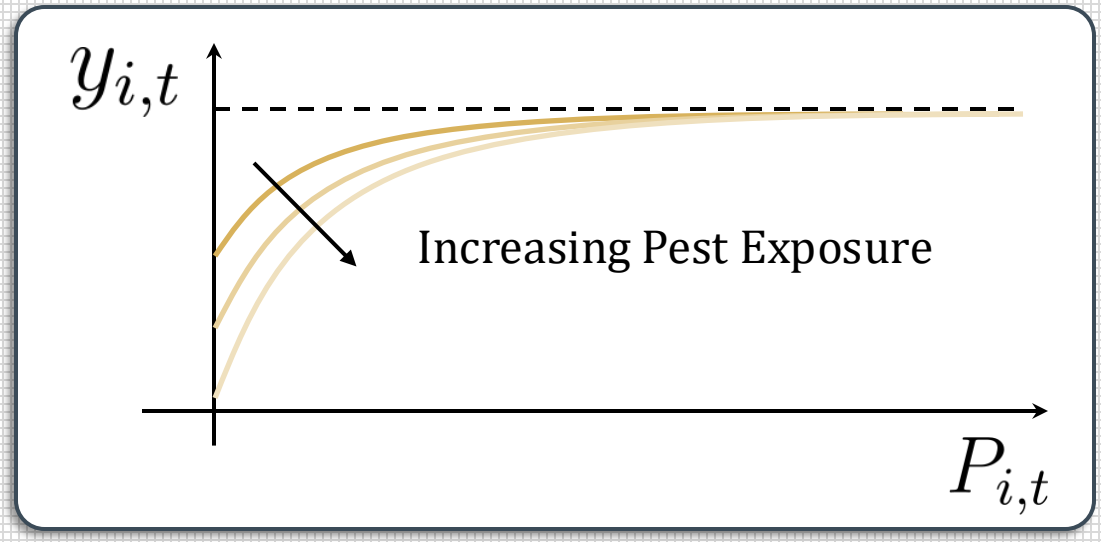
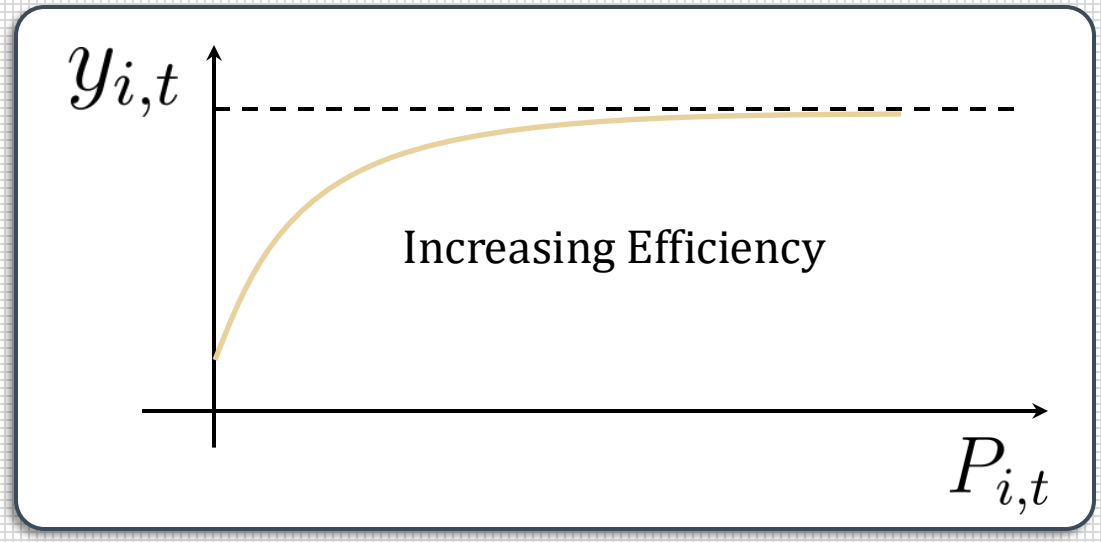

$y_{i,t}$
Increasing Pest Exposure
$P_{i,t}$


$y_{i,t}$
Increasing Efficiency
$P_{i,t}$

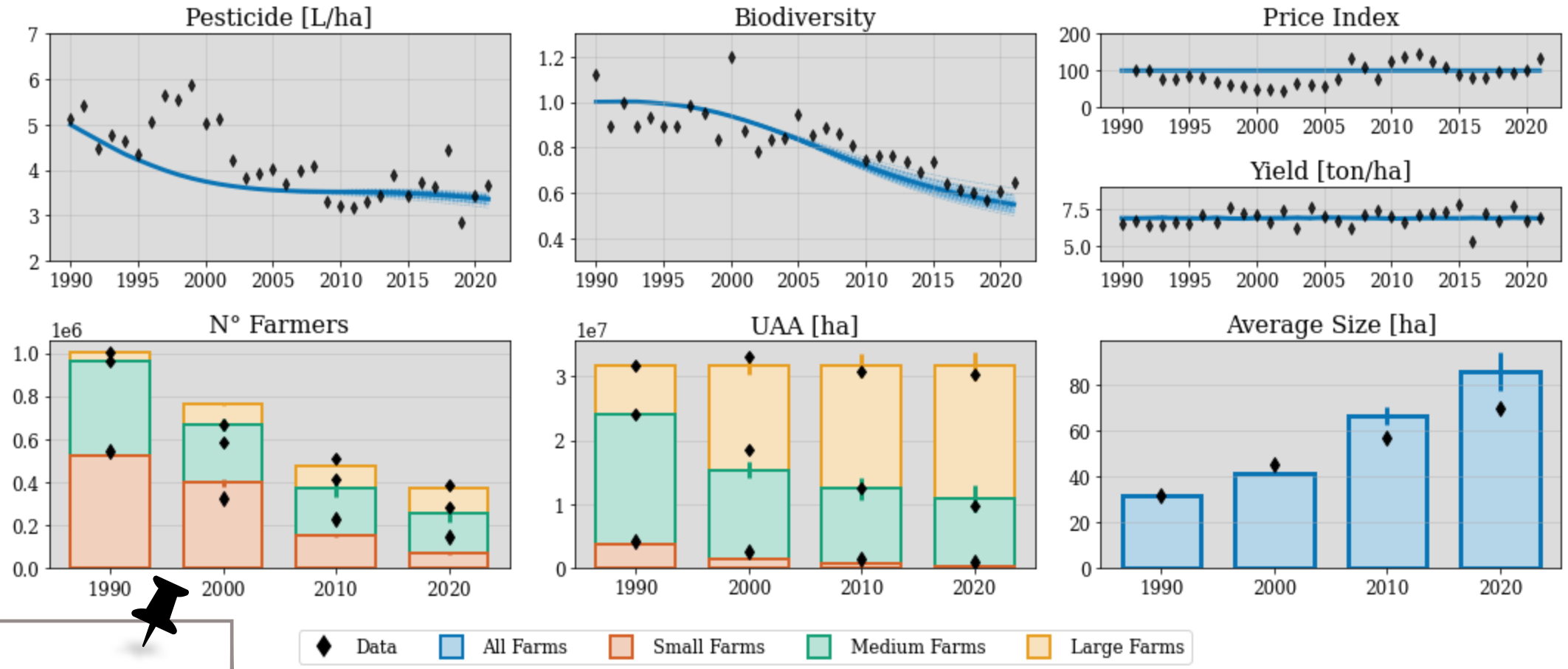
Parameters

Specific focus on:

- France
- Wheat
- 1990-2020

Section	Notation	Description	Value	Group
Initialization	N_0	Number of farms	1006120	M
	$\bar{P}_0$	Average pesticide use [kg · ha^{-1}year^{-1}]	5	M
	$\bar{y}_0$	Average yield [ton · ha^{-1}year^{-1}]	7	M
	π_0	Potential pest damage [year^{-1}]	0.3	M
	r_0	Average return on investment [year^{-1}]	0.05	M
	D	Demand [ton · year^{-1}]	21e7	E
Ecological factors	r_ε	Intrinsic growth rate [year^{-1}]	0.1	M
	μ	Carrying capacity weights	0.9	E
	a	Pest-biodiversity nonlinearity	0.5	E
Production factors	$y_{\max}$	Maximum yield [ton · ha^{-1}year^{-1}]	8.5	M
	P_{ref}	Reference pesticide [kg · ha^{-1}year^{-1}]	10	E
	std(ξ)	Production noise	0.05	M
Other economic factors	α	Price frictions		C
	p_{p}	Pesticide price [€ · kg^{-1}]	10	M
	$\mathcal{C}_{\text{O}}$	Operating costs [€ · ha^{-1}year^{-1}]	500	M
	$\mathcal{C}_{\text{NO}}$	Non-operating costs [€ · ha^{-1}year^{-1}]	600	M
	b	Economy of scale	0.9	M
	$\mathcal{S}$	Total subsidies budget [€ · year^{-1}]	8e9	M
Technology adoption	η	Profit share for technology		C
	$\mathcal{P}_{\text{ref}}$	Reference profit for technology [€ · year^{-1}]		C
	$\upsilon_{\max}$	Maximum efficiency gain [year^{-1}]		C
Behavioural factors	β	Land adjustment speed [year^{-1}]		C
	r_{ref}	Reference return on investment [year^{-1}]	0.05	E
	γ	Pesticide adjustment speed		C
	λ	Yield target adjustment speed		C

The Calibration

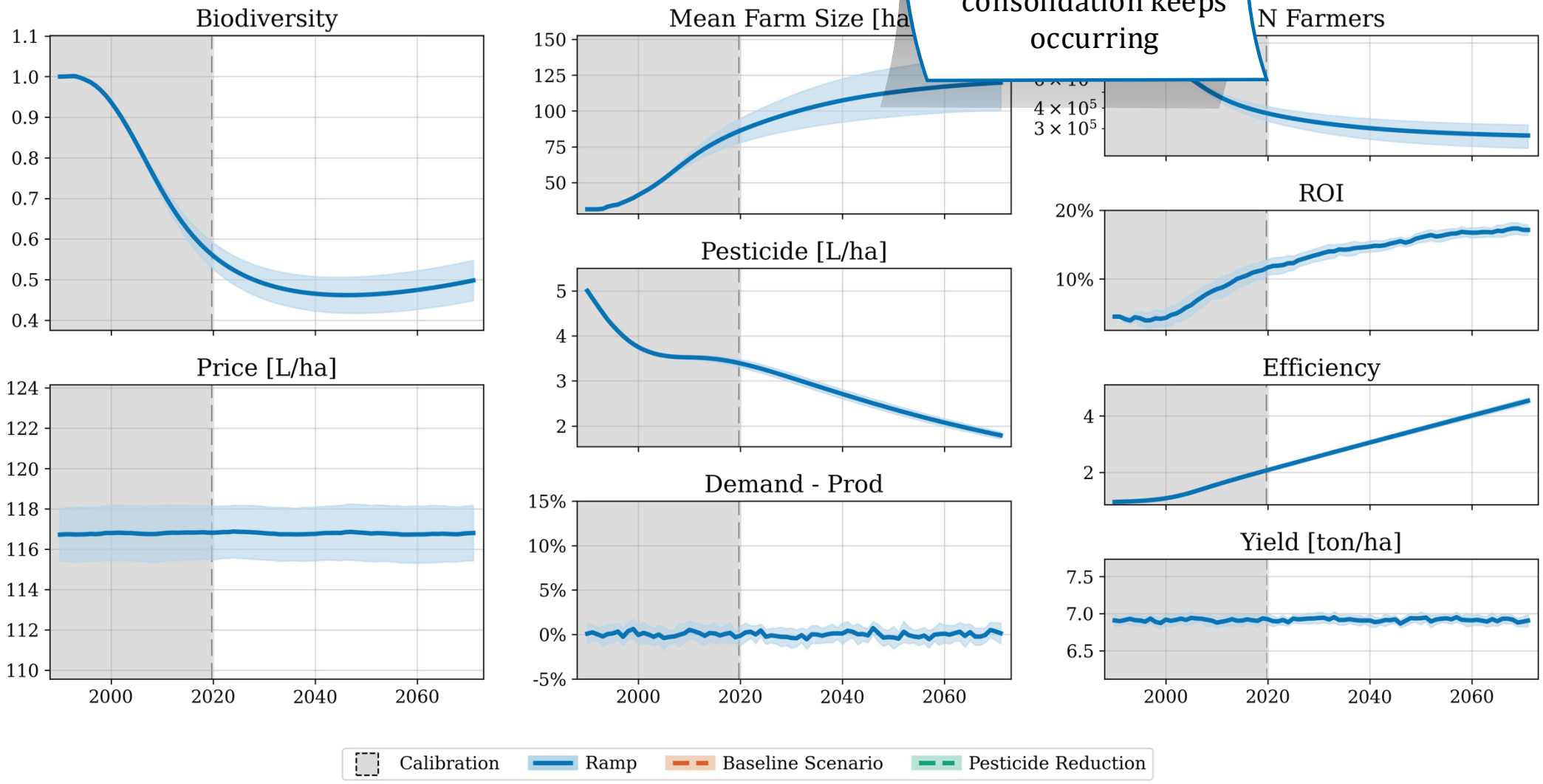


$R^2 = 0.719$

$\bar{R}^2 = 0.716$

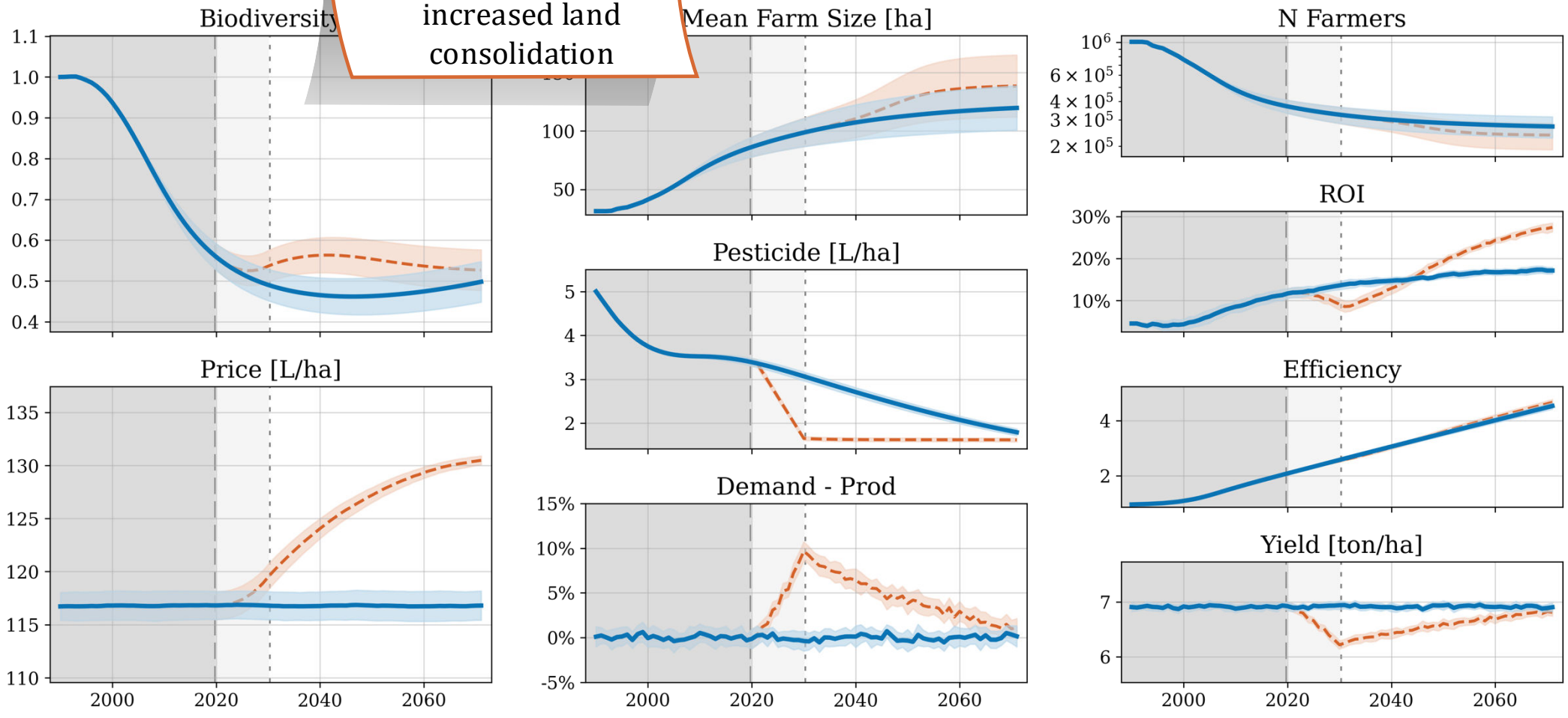
Different Policies

✓ No Policy: biodiversity decreases while land consolidation keeps occurring



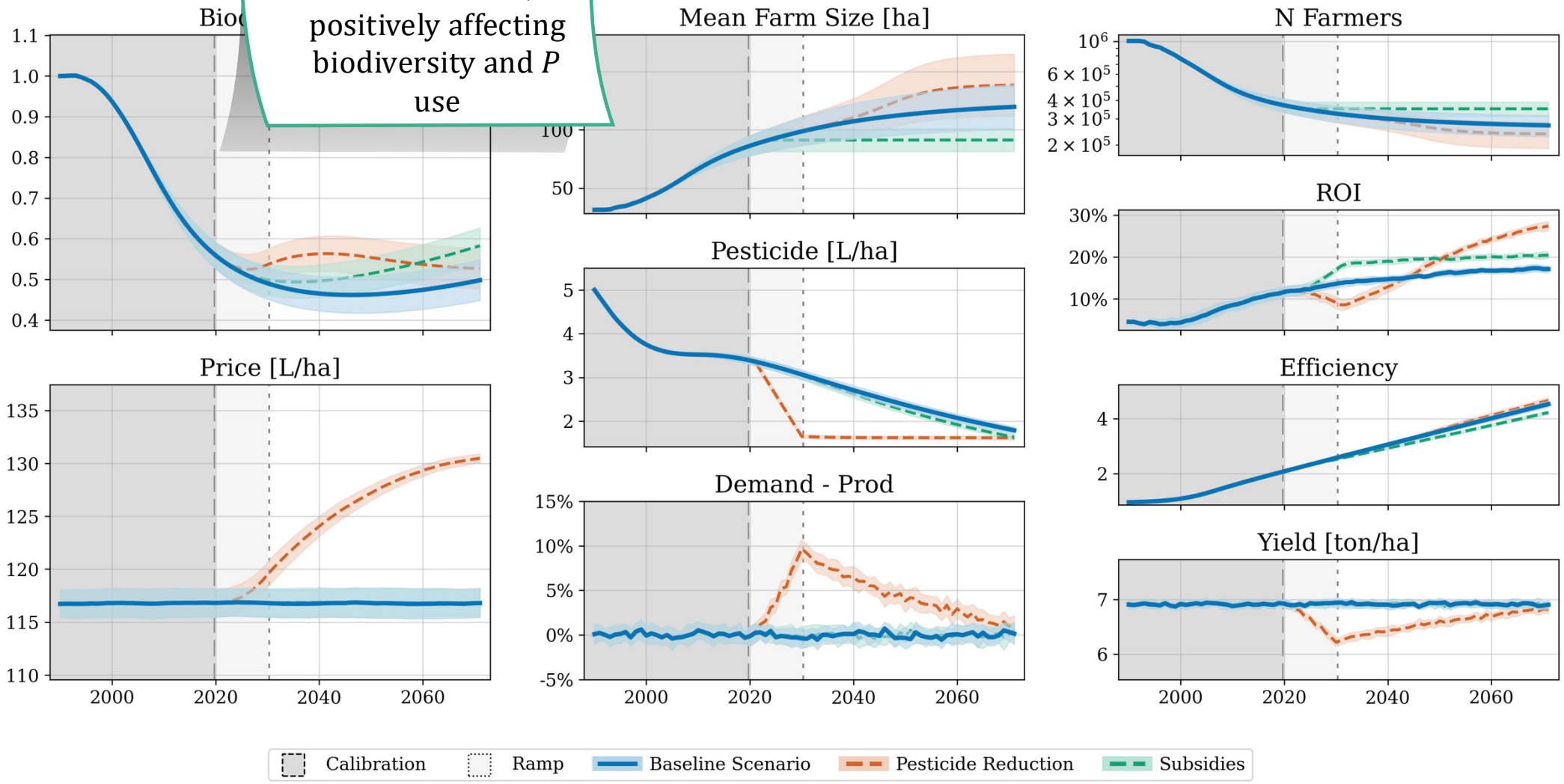
Different Polic

✓ Pesticide Reduction: the positive effect of reduced *P* use is mitigated by an increased land consolidation



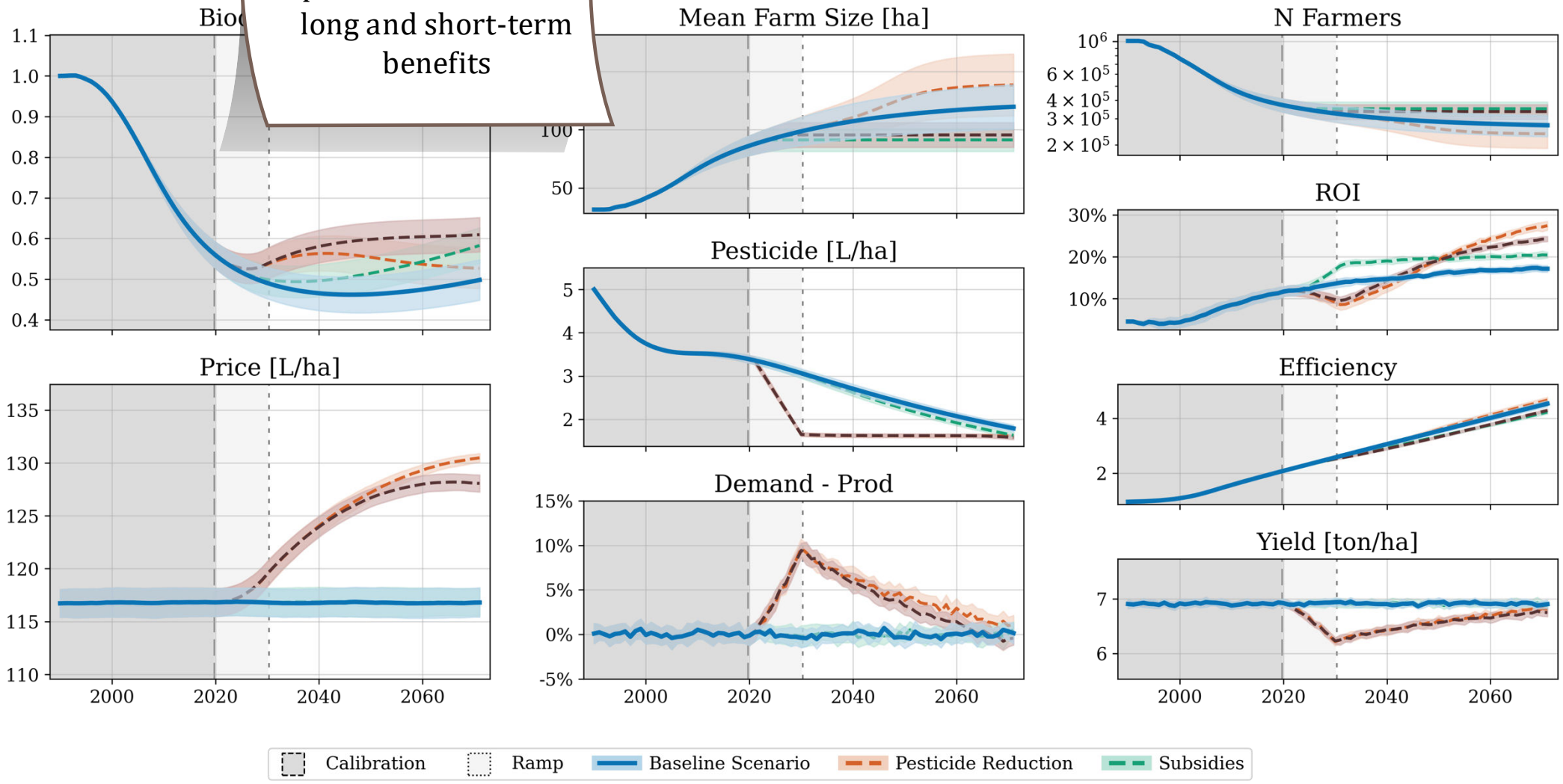
Different F

✓ Helicopter subsidies stop land consolidation, positively affecting biodiversity and *P* use

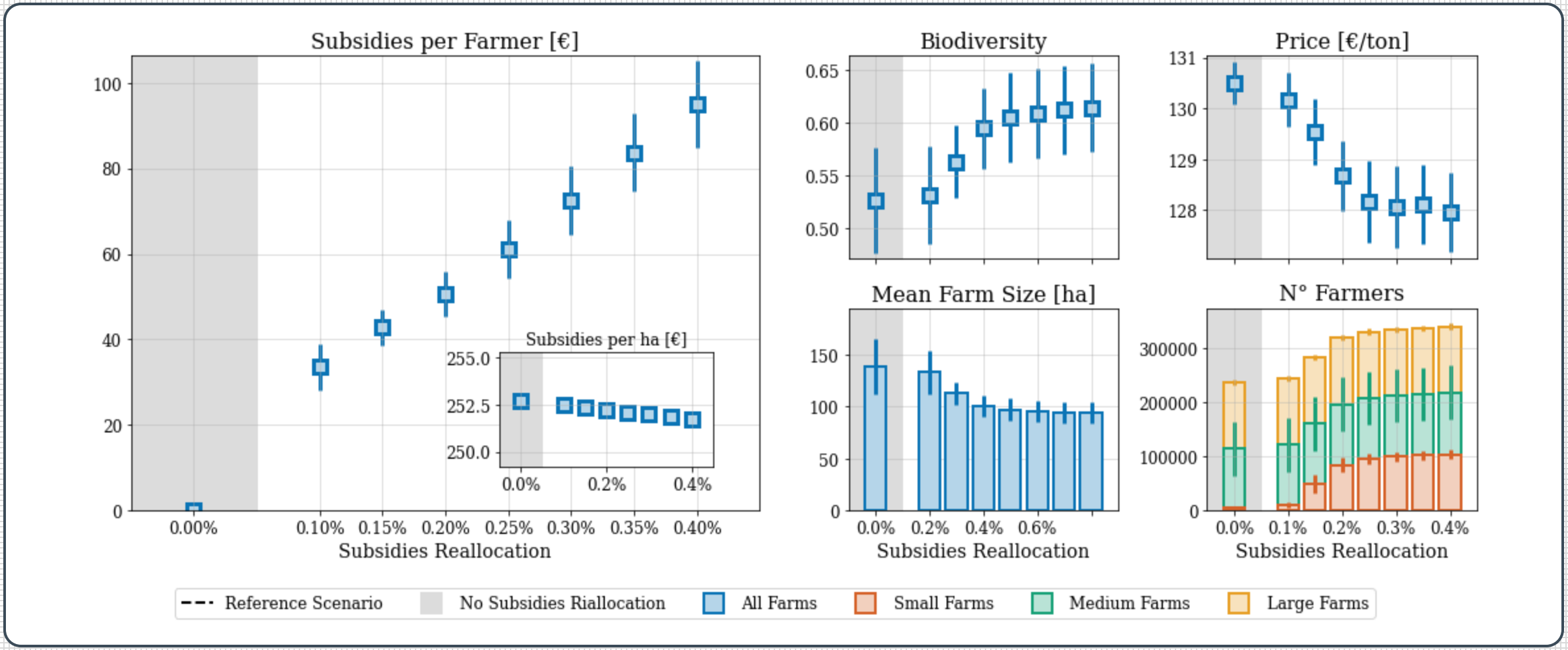


Different F

✓ Combining both policies, we balance long and short-term benefits

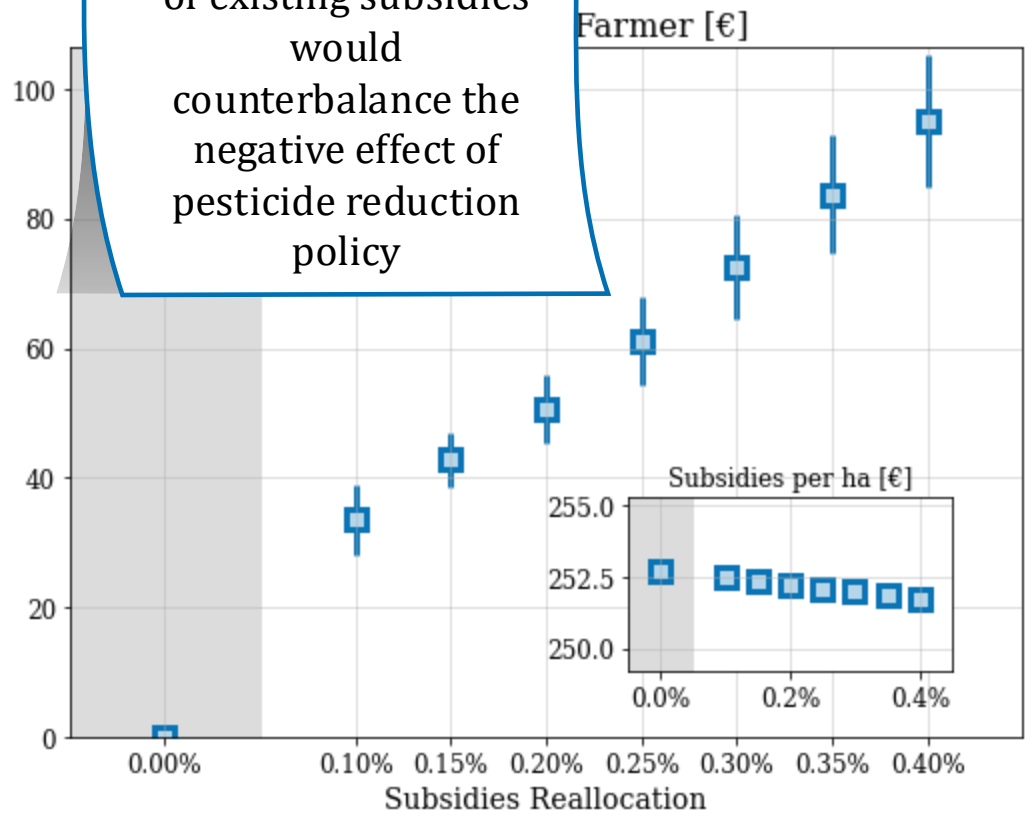


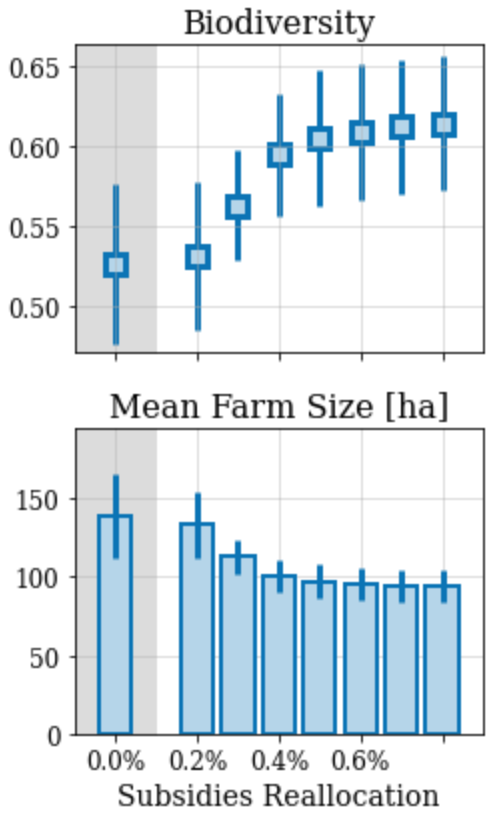
The Role of Subsidies

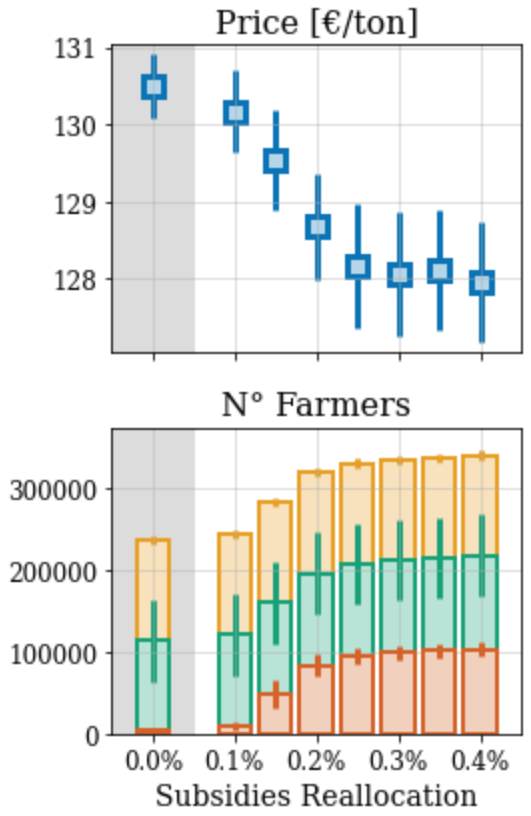


The Role of Subsidies

✓ A small reallocation of existing subsidies would counterbalance the negative effect of pesticide reduction policy



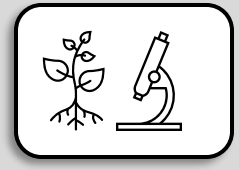




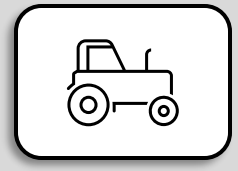
Reference Scenario | No Subsidies Riallocation | All Farms | Small Farms | Medium Farms | Large Farms

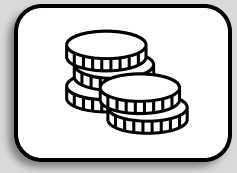
Outlooks

Ecological Models



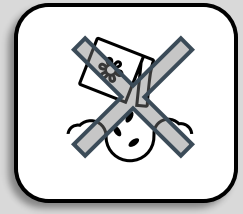
Economic Models

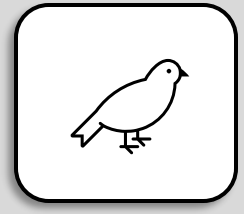


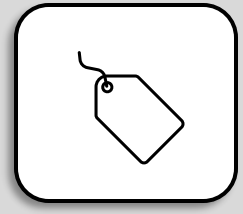


Spatial Explicit Model

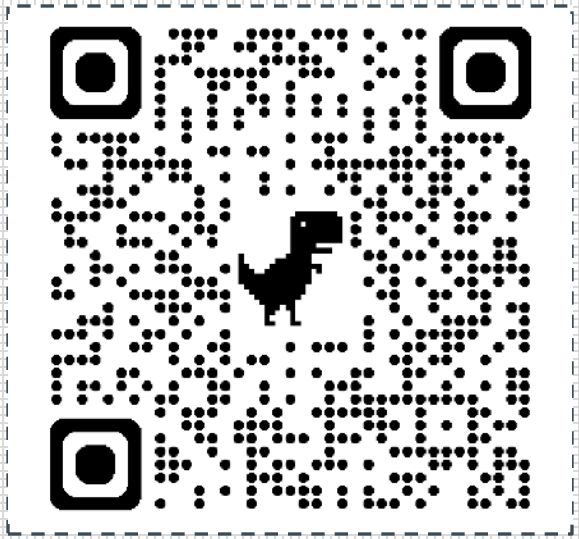
Organic Farming







Thank you

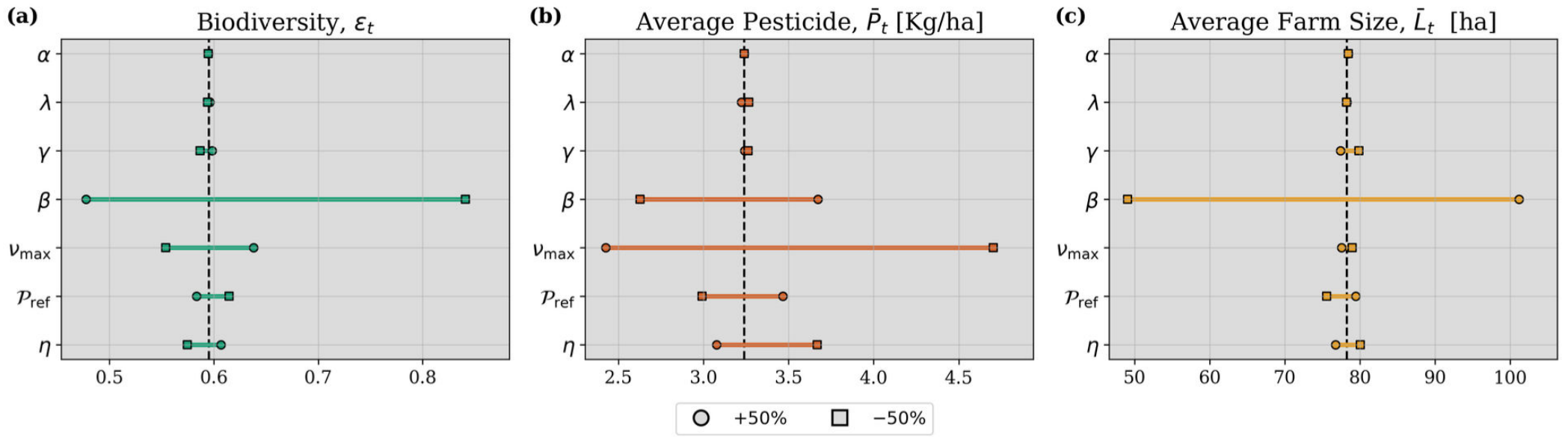


ÉCOLE POLYTECHNIQUE

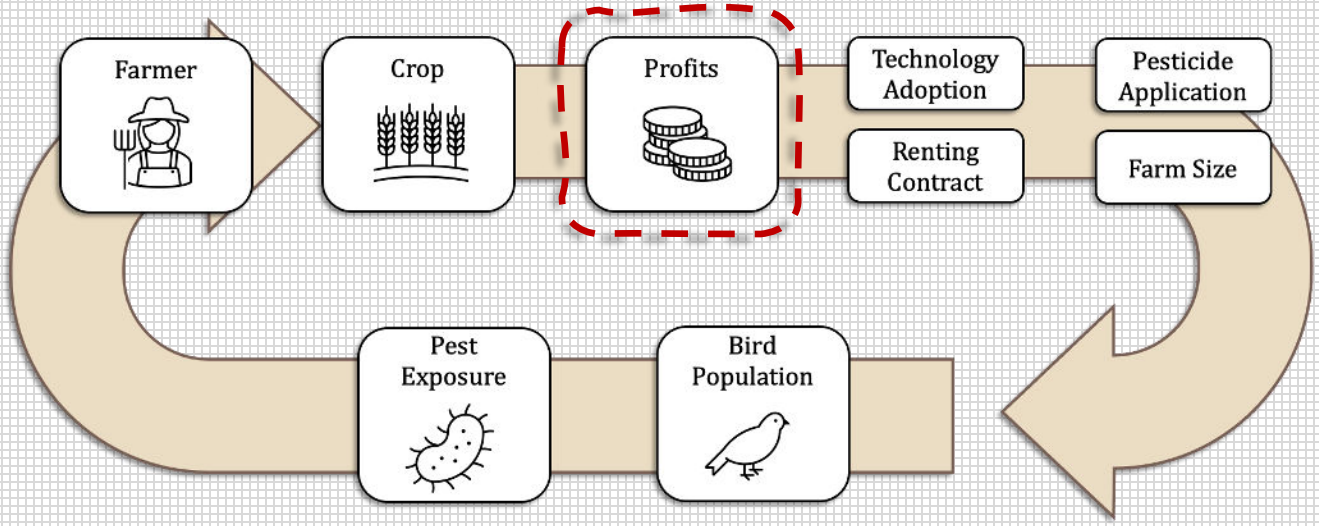
INSTITUT POLYTECHNIQUE DE PARIS

Calibration

	Description	Sampling range	Optimal	10th Percentile	90th Percentile
α	Price frictions	[0.01, 0.1]	0.08	0.03	0.09
λ	Yield target adjustment speed	[0.1, 0.5]	0.2	0.1	0.5
γ	Pesticide adjustment speed	[1.0, 3.5]	3.0	1.0	3.5
β	Land adjustment speed	[0.4, 0.5]	0.45	0.39	0.48
η	Profit share for technology	[0.05, 0.5]	0.15	0.1	0.40
$\mathcal{P}_{\text{ref}}$	Reference profit for technology	[150, 1500]	1000.0	300.0	1300.0
$\nu_{\max}$	Maximum efficiency gain	[0.05, 0.5]	0.10	0.06	0.21
$\overline{\Delta e}$	Average efficiency gain		0.025	0.019	0.028
R^2	R-squared		0.719	0.713	0.682
$\bar{R}^2$	Adjusted R-squared		0.716	0.710	0.679


(a)
Biodiversity, ε_t
(b)
Average Pesticide, $\bar{P}_t$ [Kg/ha]
(c)
Average Farm Size, $\bar{L}_t$ [ha]
α
λ
γ
β
$\nu_{\max}$
$\mathcal{P}_{\text{ref}}$
η
0.5
0.6
0.7
0.8
2.5
3.0
3.5
4.0
4.5
50
60
70
80
90
100
+50%
−50%

Outlooks



Market Price

Total Production

Goods Market

$$p_{\mathrm{m},t} = p_{\mathrm{m},t-1}\left(1+\alpha\frac{D-Y_t}{D}\right)$$

Demand

Total Costs

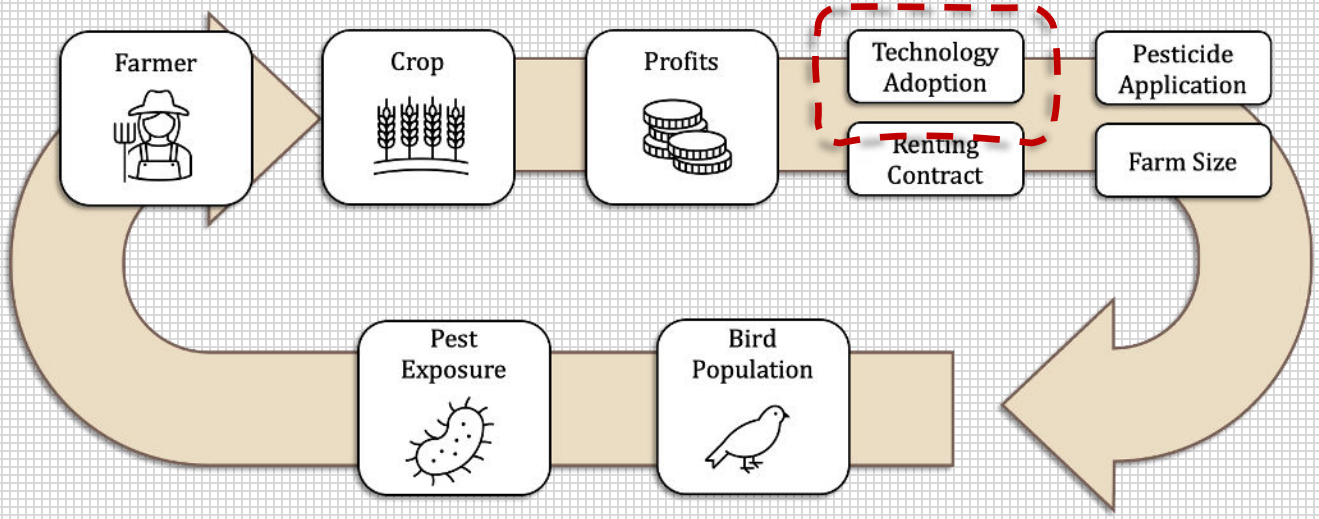
$$\mathcal{C}_{i,t} = L_{i,t}\left(p_{\mathrm{p}}P_{i,t}+\mathcal{C}_{\mathrm{o}}\right)+\left(L_{i,t}\right)^{b}\mathcal{C}_{\mathrm{no}}$$

$$\mathcal{P}_{i,t} = p_{\mathrm{m},t}Y_{i,t}-\mathcal{C}_{i,t}+\frac{L_{i,t}}{L_t}\mathcal{S}$$

Subsidies

Profits

Outlooks



Probability of a successful adoption

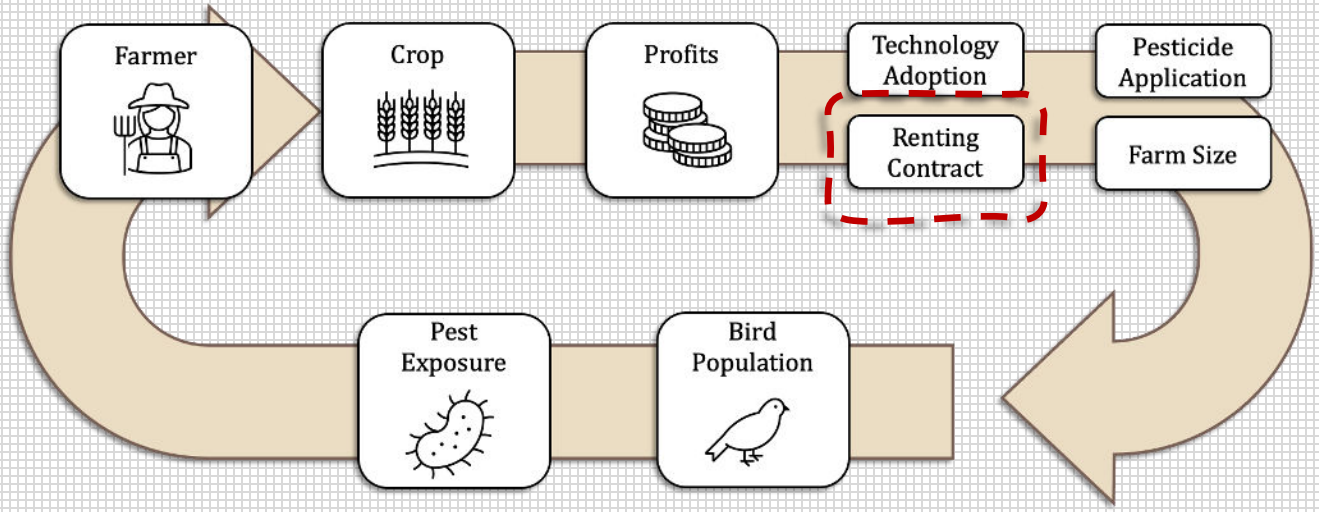
Technology Adoption

$$\mathbb{P}_{i,t}^{e} = 1 - \exp\left(-\frac{\eta \mathcal{P}_{i,t}}{\mathcal{P}_{\text{ref}}}\right)$$

$$e_{i,t+1} = e_{i,t} + v_{i,t}$$

Efficiency gain

Outlooks



Demand for land expansion

Return on Investment

Land Rental Market

$$L_{i,t}^{-} = \frac{\beta}{1 + \frac{r_{\text{ref}}}{r_{\text{ref}} - r_{i,t}}} L_{i,t}$$

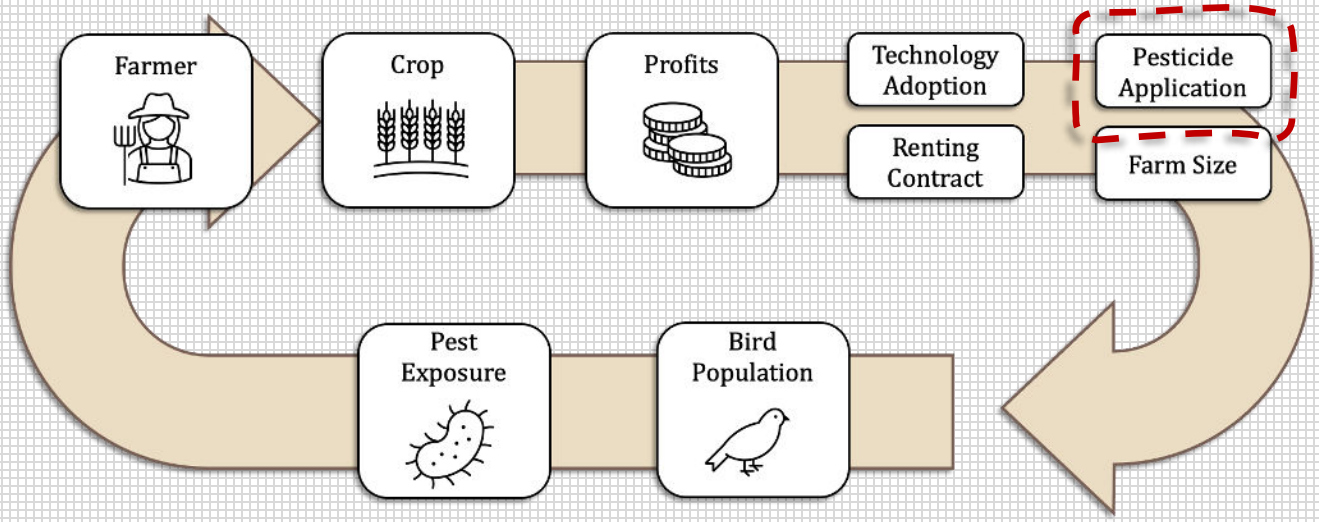
$$L_{i,t+1} = L_{i,t} - L_{i,t}^{-}$$

$$\tilde{L}_{i,t}^{+} = \frac{\beta}{1 + \frac{r_{\text{ref}}}{r_{i,t} - r_{\text{ref}}}} L_{i,t}$$

$$L_{i,t+1} = L_{i,t} + L_{i,t}^{+}. \quad \text{where} \quad L_{i,t}^{+} = \tilde{L}_{i,t}^{+} \min\left(1, \frac{\tilde{L}_{t}^{+}}{L_{t-1}^{\text{leftover}} + L_{t}^{-}}\right)$$

$$L_{t}^{\text{leftover}} = L_{t-1}^{\text{leftover}} + L_{t}^{-} - L_{t}^{+}$$

Outlooks



Pesticide Use

$$P_{i,t+1} = P_{i,t}\left(1 + \gamma \frac{\tilde{y}_{i,t} - y_{i,t}}{y_{i,t}}\right)$$

Yield Target

$$\tilde{y}_{i,t+1} = \tilde{y}_{i,t}\left(1 + \lambda \frac{p_{\mathrm{m},t} - p_{\mathrm{m},t-1}}{p_{\mathrm{m},t}}\right)$$