An Agent-based Approach to the Ex-Ante Evaluation of Public Policies

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Ex-ante evaluation is critical to policy-making

- Providing evidence-based policy alternatives
- Forecasting and listing their potential impacts

Ways of organizing ex-ante evaluation of policies

	Actuality	Generality	Cost	Duration	Controllability
Policy piloting 政策试点	High	Low	High	Very long	Low
Field experiment 实地实验	Moderate	Very low, ad hoc	Moderate	Long	Moderate
Policy simulation 政策模拟	**Low**	**High**	**Low**	**Very short**	**High**

Simulation is a powerful tool for policy evaluation

- Especially policies with wide coverage, high uncertainty, long-lasting influence.
- Not yet widely used for agricultural policies.

Existing simulations focuses on the macro level

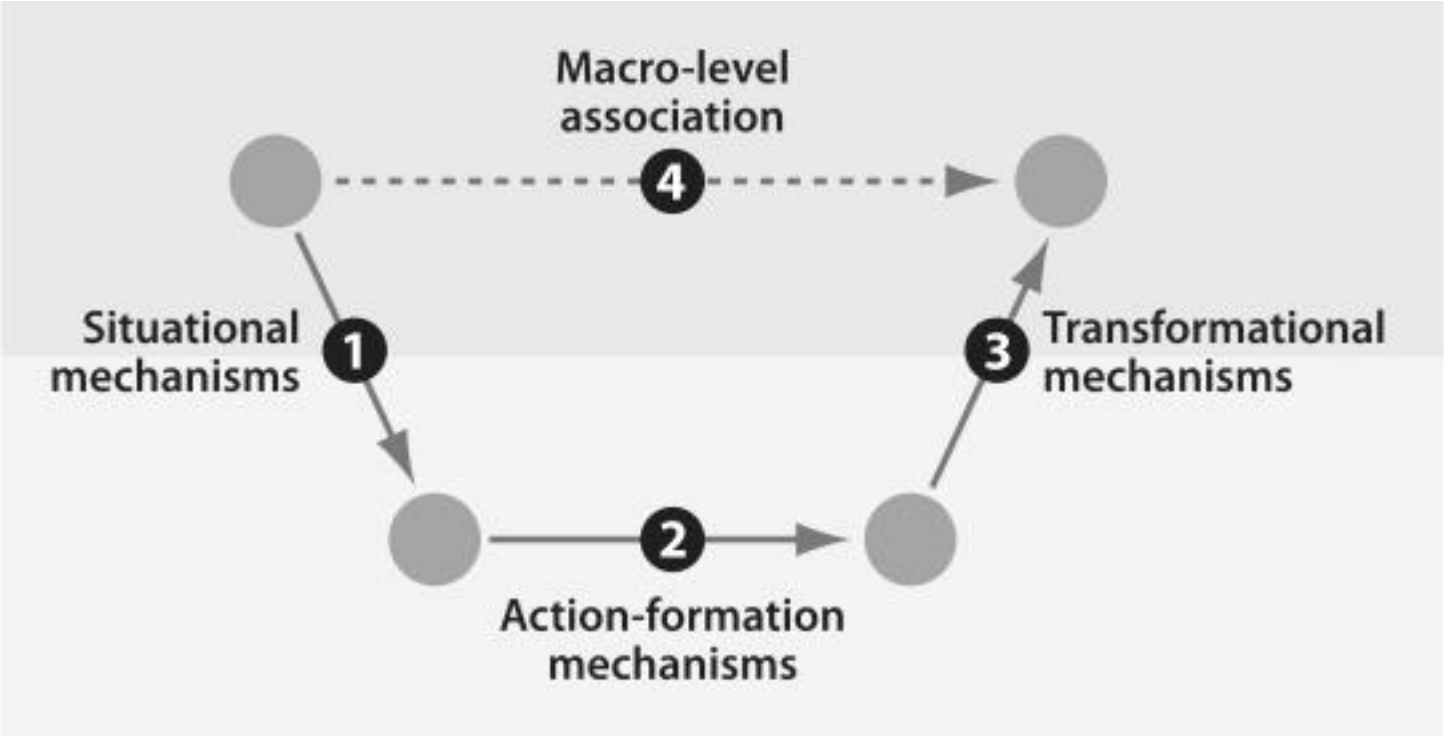
Typical models

- General/partial equilibrium (CGE) models
  - aggregated representations of the entire economy in equilibrium
- Integrated assessment models (IAMs)
  - a representation of key processes in the human and natural systems and their interactions.

Key drawbacks

- Fail to consider micro-level behavior and interactions that underlies the transition from a policy to its impacts.
- Underestimating the uncertainties.

Micro-level interactions matter in policy evaluation



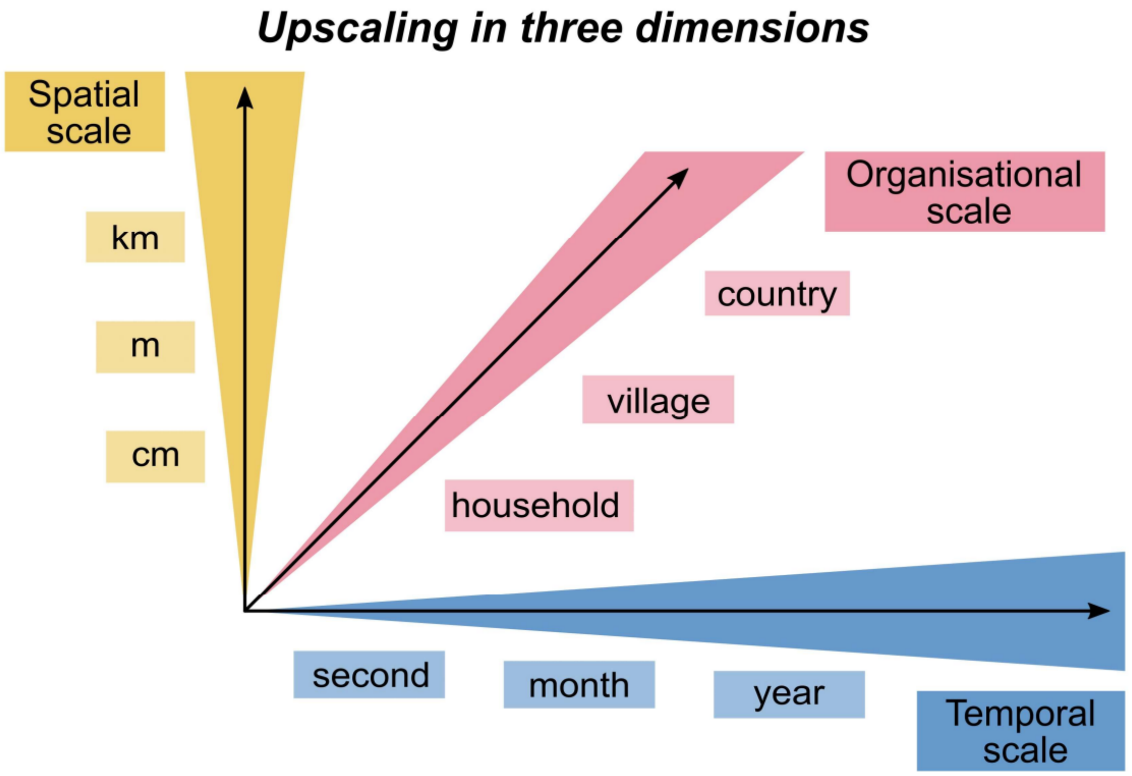
Coleman’s Boat

Agent-based simulation can fill this gap

- Agent-based simulation deals with micro level behavior and interactions.
- Agent-based Modelling (ABM) provides more realistic representations of socio-economics by simulating the economy through the interactions of a number of heterogenous agents, on the basis of specific behavioral rules.
- Integrate ABM with macro-level models (e.g., IAM)

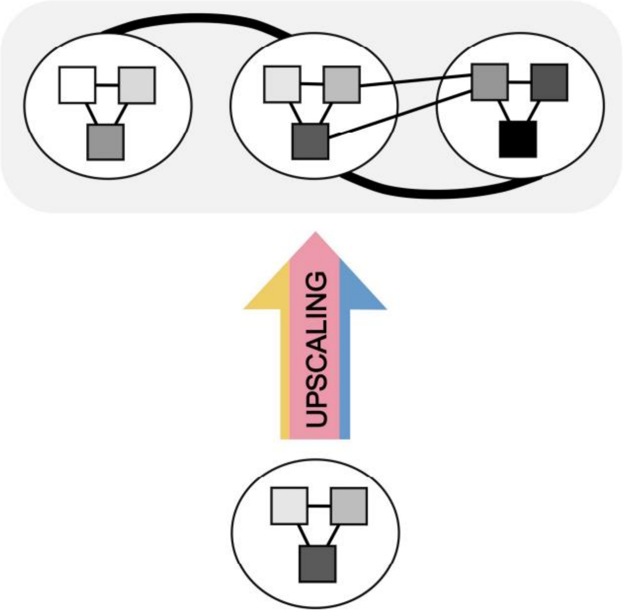
Key challenge of using ABM for micro level evaluation

- How to scale individual level outcomes up to the regional level?



Approaches to upscaling

Increasing extent



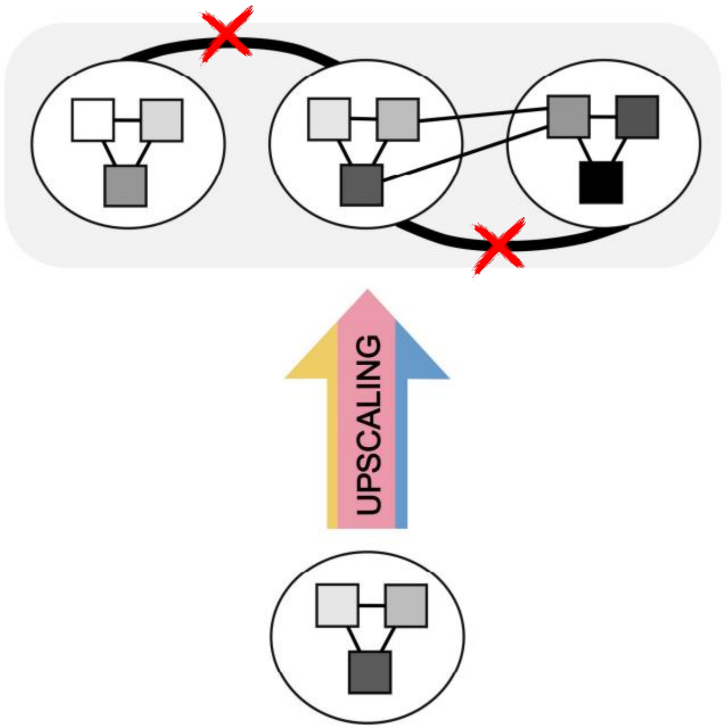
Increase heterogeneity, increase interactions

Decreasing resolution

Decrease heterogeneity, decrease interactions

Our practice to propose

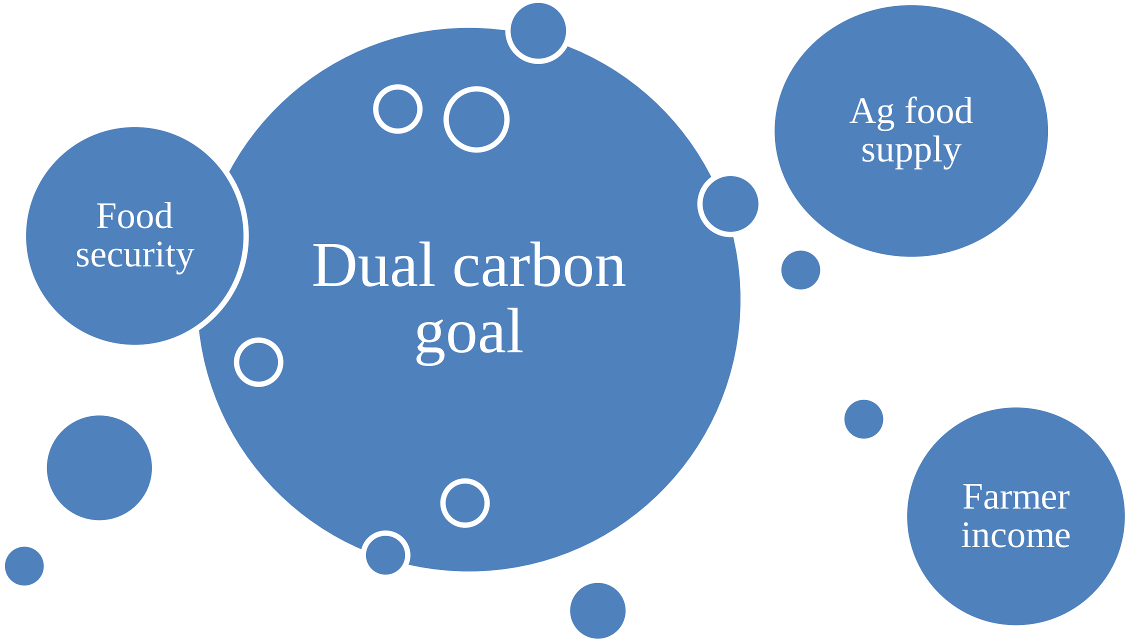
- Increasing extent by
  - Keeping heterogeneity while deriving the distribution of micro level agents
  - Leaving interactions unaddressed



An Application: An Agent-based Evaluation of Carbon Mitigation Policies in Agriculture

Background: China's dual carbon national goal

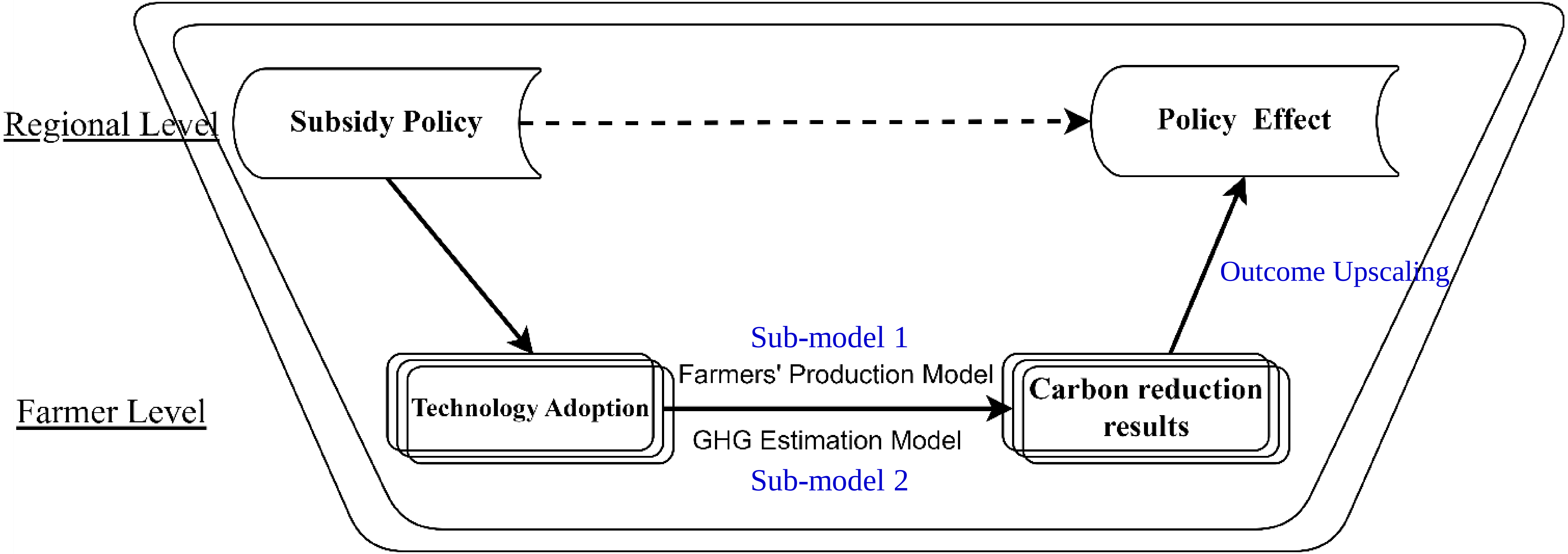
- Peak carbon emissions by 2030 and carbon neutrality by 2060.
- Carbon emissions in agriculture account for 17% of the total carbon emissions.



Research purposes

- A policy of subsidizing the use a low-carbon farming technology
  - Technology: slow-release fertilizer
  - Area: Jianghan Plain (including six cities in Hubei Province)
- Questions to address
  - What are the impacts on carbon emissions and food production
  - How efficient is the subsidy in terms of cost and benefit
  - Which farmers the policy should target

Modelling framework



Sub-model 1: Farmers' production model

- Farmers are rational decision-makers
- Maximizing their profits subject to cost constraints of capital, labor, land
- Simulated by an optimization model with
  - Objective function
  - Decision Variables and Constraints

(1) Objective function: profits

Famers' profits consist of those from production and carbon reduction.

$$\Pi = \Pi_{prod} + \Pi_{carbon}$$

$$\Pi_{prod} = Y_{prod} - C_{prod}$$

$$\Pi_{carbon} = Y_{carbon} - C_{carbon}$$

Carbon reduction profit

- CCER (Chinese Certified Emission Reduction): difference between base-period value and report-period value

$$CCER = Emission_{t0} - Emission_{t1}$$

- Carbon emission reduction profits: per unit carbon transaction price minus per unit carbon transaction fee

$$\pi_{carbon} = CCER \cdot Price_{carbon} \cdot (1 - \theta)$$

(2) Cost constrains

- Yield in Cobb-Douglas function from

$$Y = \min\{\frac{Labor}{a_1}, \frac{Land}{a_2}, \frac{Fertilizer}{a_3}, \frac{Tools}{a_4}, \frac{Machinery}{a_5}, \frac{Pesticide}{a_6}, \frac{Seeds}{a_7}\}$$

- Costs involved production
  - $C_{tradition} = C_{other} + Tools + Fertilizer$
  - $C_{deepPlacement} = C_{other} + Fertilizer + Tools \cdot Subsidy_{deep}$
  - $C_{slowRelease} = C_{other} + Tools + Fertilizer \cdot Subsidy_{slow}$

The optimization model

$$max(\pi_{product} + \pi_{carbon})$$

$$s.t.\begin{cases} \pi_{product} = Y - ProductCost \\ Y = min\{\frac{labor}{a_1}, \frac{land}{a_2}, \ldots, \frac{film}{a_8}\} \\ ProductCost = c_{materials} + c_{labor} + c_{land} \\ c_{labor} = \frac{M}{1+e^{-k_1(labor-l_1)}} - \frac{M}{1+e^{k_1 l_1}} \\ c_{land} = \frac{N}{1+e^{-k_2(land-l_2)}} - \frac{N}{1+e^{k_2 l_2}} \\ c_{materisals} = c_{lowCarbon} \cdot Subsidy + c_{others} \\ CCER = Emission_{t0} - Emission_{t1} \\ \pi_{carbon} = CCER \cdot Price_{carbon} \cdot (1-\theta) \end{cases}$$

Sub-model 2: GHG emission estimation model

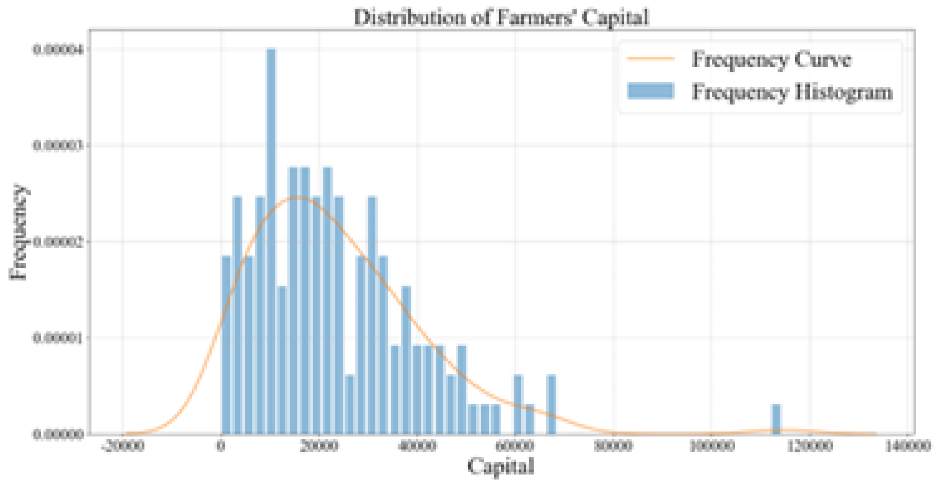
$$Emission_{perUnit} = \beta_0 + \sum_{1}^{8} \beta_i X_i + \mu$$

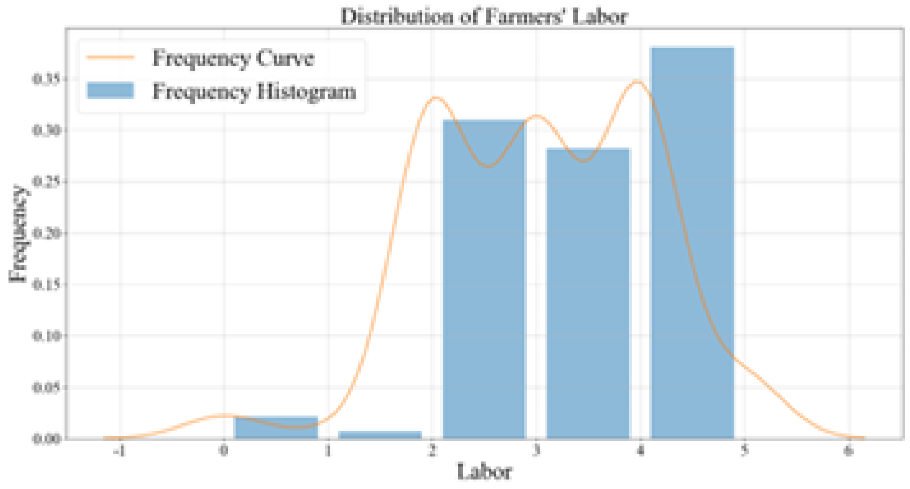
- We use field data to estimate the parameters
- Dependent variable: Carbon emissions per unit area of land
- Independent variable: Field management variables

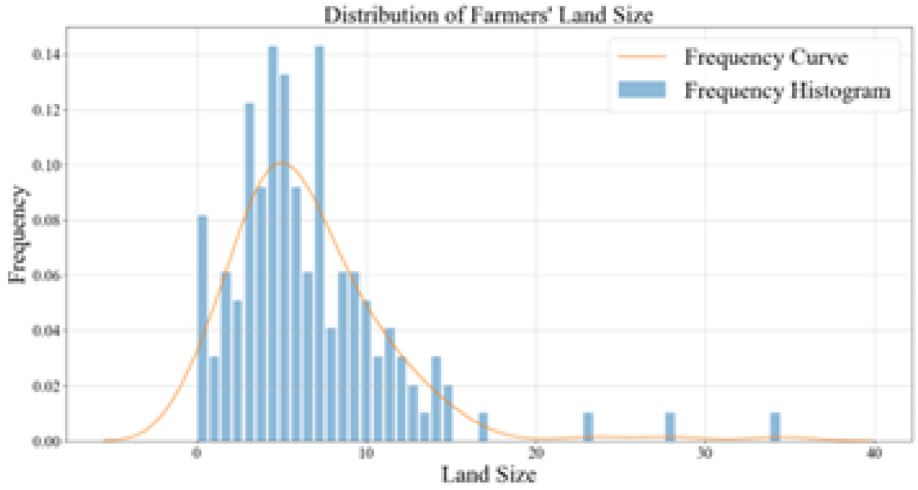
Upscaling: Steps of upscaling model outcomes

- Classifying farm households according to their three key attributes: labor, landholding and capital
- Extracting the distribution of farm households by the three attributes in the region focused (i.e., Jianghan Plain with over 110 thousand farm households)
- Estimating the number of farm households for each attribute combination in the region

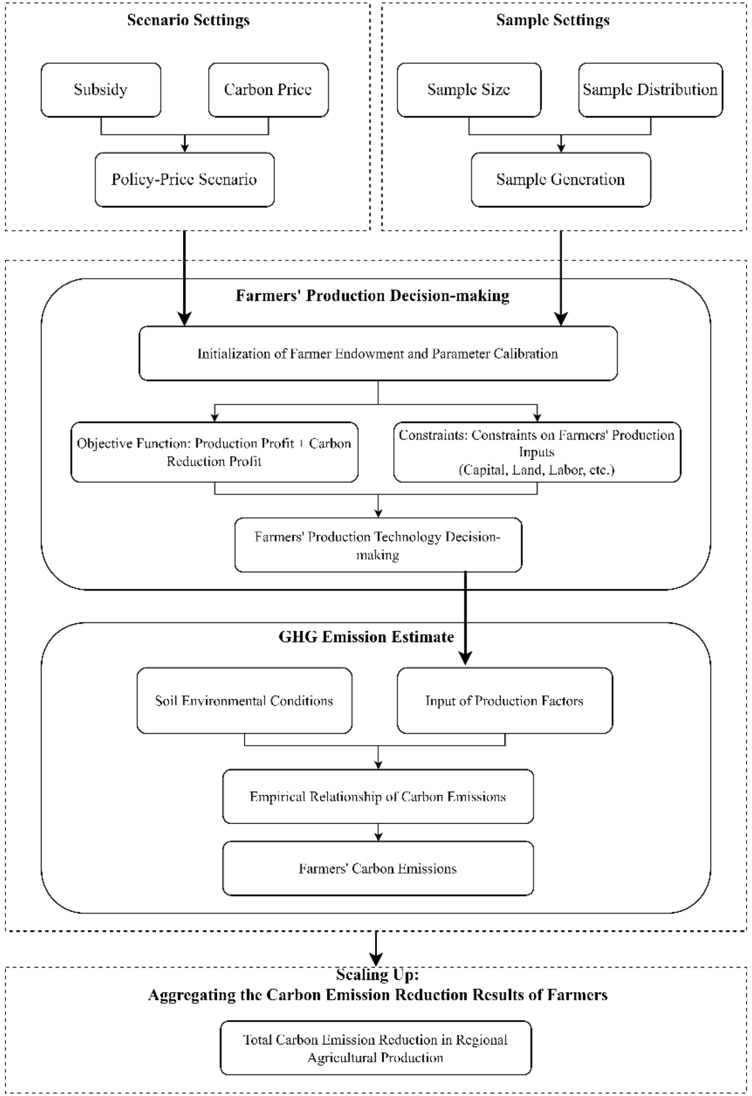
Distribution of farm households for each attribute

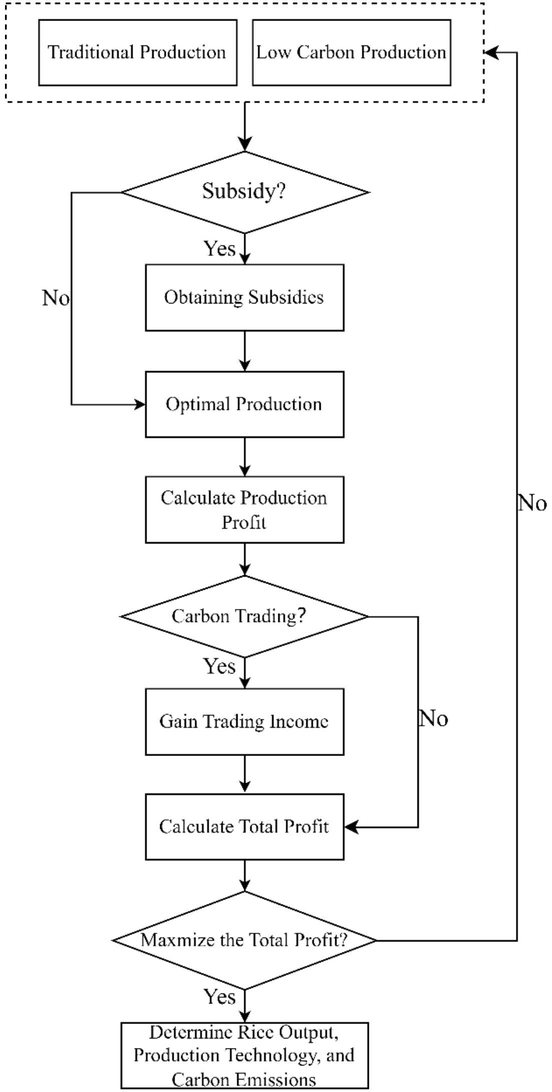






Overview of the model and flowchat of running





Variables involved in the model

Variable Type	Variables	Description
Input Variables	capital	Farmers' initial capital(yuan)
	labor	Farmers' initial labor force
	land	Farmers' initial land size(mu)
	invest_ratio	Farmers' investment budget as a share of initial capital
	density	Farmers' rice planting density(plant/mu)
	irrigation	Number of times farmers irrigate rice(times)
	$price_{carbon}$	Carbon trading price(yuan)
	Θ	Transaction cost factor
	Subsidy	Subsidy ratio
	$price_{self\_labor}$	Wages for own labor use(yuan)
	$price_{hire\_labor}$	Price of hired labor(yuan)
	$price_{self\_land}$	Land rent of self operated land(yuan)
	$price_{transfer\_land}$	Land rent of transfer land(yuan)
	accum_temp	Soil accumulation temperature(℃)
	soil_organic	Soil organic matter (g/kg)
	shannon	Soil microbial diversity index

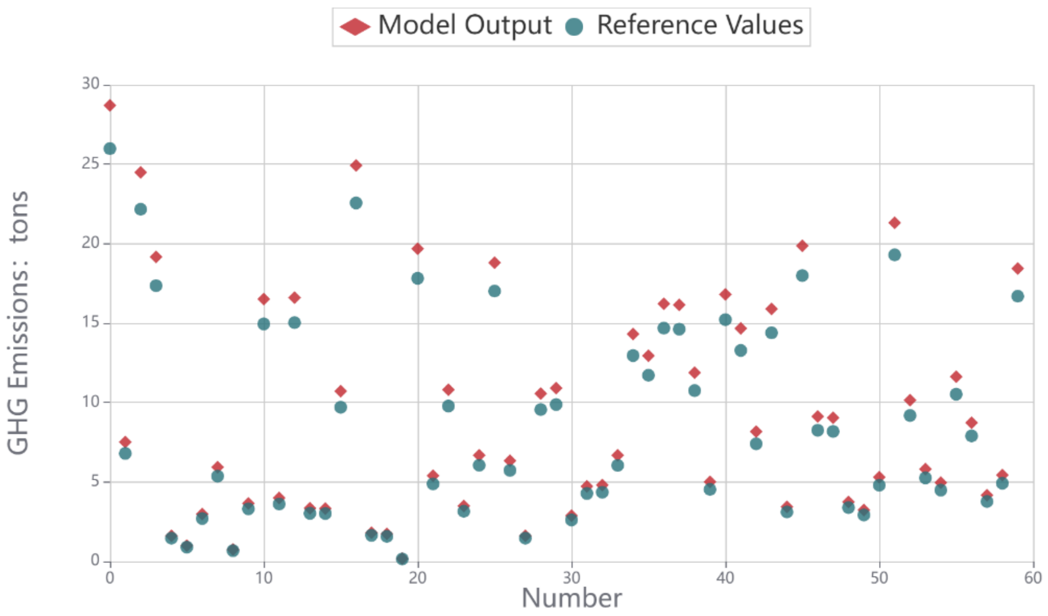
Variable Type	Variables	Description
Intermediate variables	tech_emission	Carbon emissions per unit area for each technology(ton/mu)
	base_emission	Baseline carbon emissions(tons/acre)
	$\beta_1, \beta_2, \dots, \beta_8$	Parameters of the carbon emission estimation function
	$\alpha_1, \alpha_2, \dots, \alpha_8$	Input-output coefficient of each factor
	M, k_1, l_1	Parameters of the labor cost function
	N, k_2, l_2	Parameters of the land cost function
	$cost_1, cost_2, \dots, cost_8$	Input of various factors of production (yuan)
Output Variables	$carbon\_reduction_i$	Farmers' carbon emission reduction(tons)
	$profit_i$	Farmers' total profit(yuan)
	$tech\_type_i$	Types of technologies adopted by farmers
	carbon_reduction_all	Total regional carbon emission reduction(million tons)
	policy_cost	Total cost of policy implementation(million yuan)
	policy_benefit	Total benefits of policy implementation(million yuan)
	$tech\_num_1, \dots, tech\_num_3$	Total number of technical adopters in each category(persons)

Parameter calibration with real-world data

Parameter Type	Parameters	Value	Source
Determine the parameters	capital	[5, 536540]	National Survey of Fixed Observation Points in Rural Areas
	labor	[0, 8]	National Survey of Fixed Observation Points in Rural Areas
	land	[0, 53.1]	National Survey of Fixed Observation Points in Rural Areas
	invest_ratio	[0, 1]	National Survey of Fixed Observation Points in Rural Areas
	density	[20, 30]	Measured data from low carbon rice crop trial sites
	irrigation	[5, 15]	Measured data from low carbon rice crop trial sites
	$price_{carbon}$	50, 150, 400	China Carbon Trading Platform, EU Carbon Trading Platform
	Θ	0.4	Expert consultation
	$S_{SlowRelease}$	0, 0.2, 0.7	Local government subsidy documents
	$S_{DeepPlacement}$	0, 0.35, 1	Local government subsidy documents
	$price_{self\_labor}$	78	Compendium of Costs and Benefits
	$price_{hire\_labor}$	151	Compendium of Costs and Benefits
	$price_{self\_land}$	100	Compendium of Costs and Benefits
	$price_{transfer\_land}$	200	Compendium of Costs and Benefits
	accum_temp	[5000, 6000]	Measured data from low carbon rice crop trial sites
	soil_organic	[14.22, 20.61]	Measured data from low carbon rice crop trial sites
	shannon	[1.72, 6.28]	Measured data from low carbon rice crop trial sites
Uncertain parameters	$\beta_1, \beta_2, \ldots, \beta_8$	See Appendix for details	Parameter estimation of multiple linear regression equations
	$\alpha_1, \alpha_2, \ldots, \alpha_8$	See Appendix for details	Mean value of input-output coefficient of each low-carbon rice farming pilot
	M, k_1, l_1	See Appendix for details	Parameter estimation of nonlinear regression equation
	N, k_2, l_2	See Appendix for details	Parameter estimation of nonlinear regression equation

Validation of the model

- Method: Emission factor method
- Sample: 60 households were randomly selected
- Results: RMSE = 1.30



Application to policy scenarios

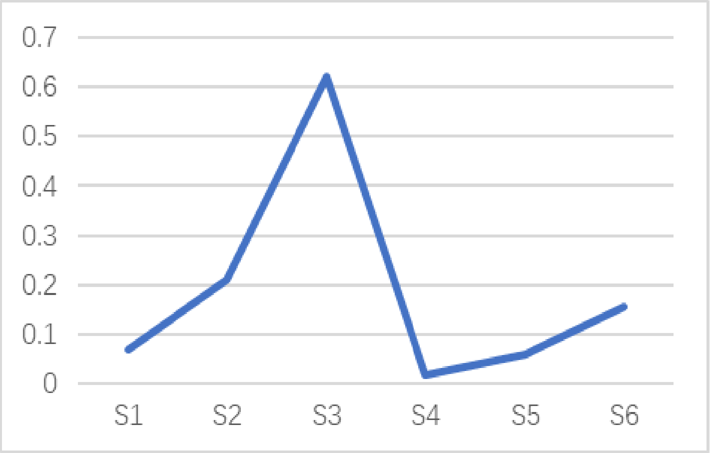
Scenario	Subsidy Ratio	Carbon Price
A1（Baseline）	0	50 yuan/ton
A2	0	150 yuan/ton
A3	0	400 yuan/ton
S1	20%	50 yuan/ton
S2	20%	150 yuan/ton
S3	20%	400 yuan/ton
S4	70%	50 yuan/ton
S5	70%	150 yuan/ton
S6	70%	400 yuan/ton

Result: Carbon reduction effect

Scenario	Carbon Emission Reduction in total (tons)	Carbon Emission Reduction per household (tons)
A1	0.00	0.00
A2	0.00	0.00
A3	0.00	0.00
S1	22679.74	0.02
S2	22794.24	0.02
S3	25997.12	0.02
S4	778778.73	0.68
S5	779605.01	0.68
S6	779808.45	0.68

Result: Cost and benefit of the subsidy

Scenario	Subsidy	Carbon emission reduction
S1	1627.94	113.40
S2	1629.10	341.91
S3	1675.29	1039.88
S4	199729.80	3893.89
S5	199932.30	11694.08
S6	199966.60	31192.34



Result: farmers adopting the technology

Variance Analysis of Three Types of Resource Endowments for Farm Households

Endowment Type	Technology adoption	mean	sd	F	P-Value
Capital	Traditional	27645.25	26215.37	37773.59	0.00***
	Slow-release Fertilizer	202665.88	171858.44		
Labor	Traditional	2.95	1.24	259.40	0.00***
	Slow-release Fertilizer	3.58	0.81		
Land	Traditional	4.93	3.50	16.91	0.00***
	Slow-release Fertilizer	4.19	2.15		

Conclusions

- Agent-based simulation can be a powerful approach for conducting accurate ex-ante evaluation of agricultural policies.
- Compared to other approaches, it can provide more precise estimation by delving into micro-level mechanisms and leads to more concrete action-informed policy implications.

- **Thank you for listening.**
- **Questions and comments are welcomed.**