turning knowledge into practice

Modeling Marginal Abatement Cost Curves for Agricultural GHG Emissions when Producers Adopt Multiple Mitigation Options

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Overview of Presentation

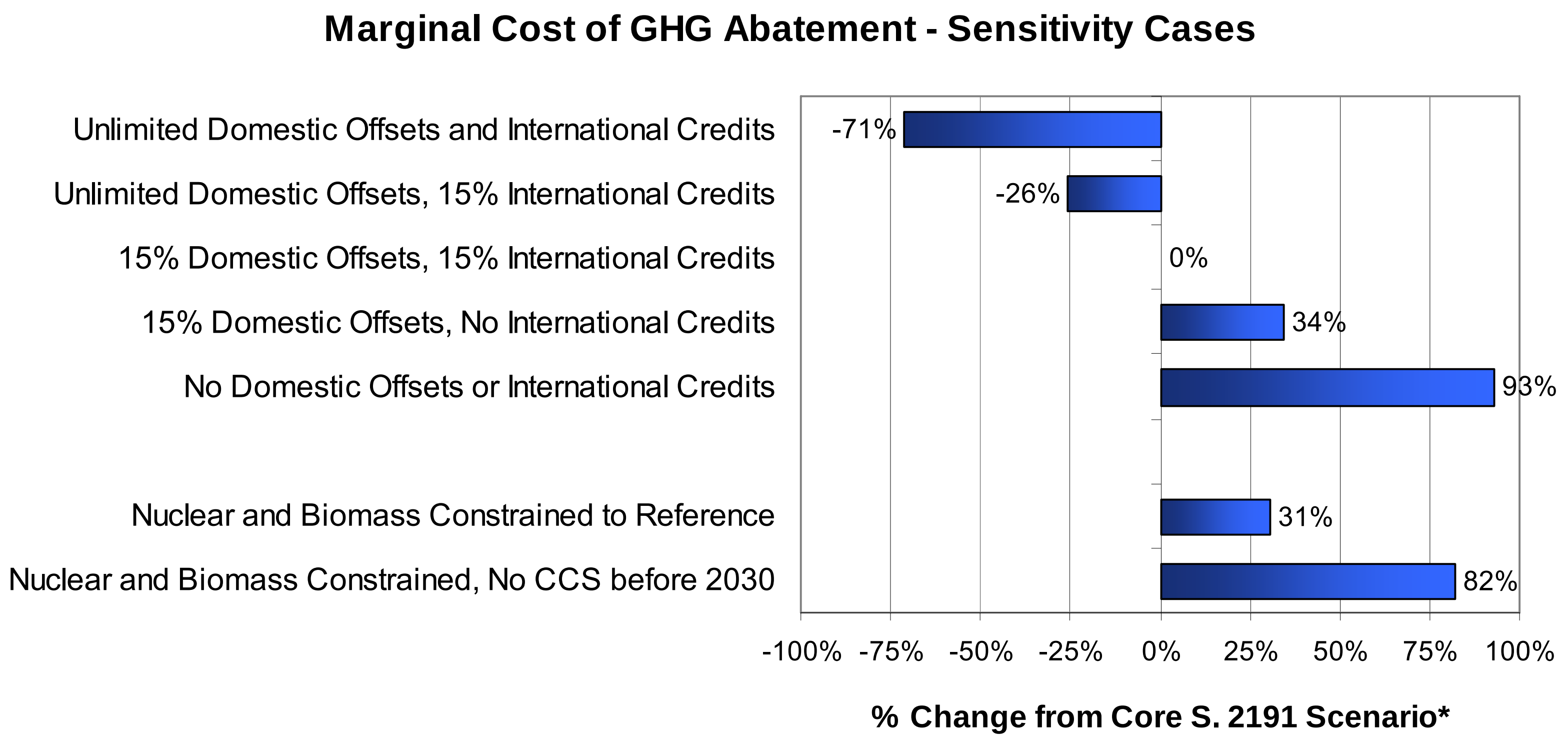
- Motivation
- Methodology
- China case study
- Initial results
- Initial conclusions

Introduction

- Cropland is a large emissions source with substantial technical and economic mitigation potential
- Agriculture has the potential to be cost-competitive in near-term and long-term abatement portfolios, e.g.,
  - 7-22% of cumulative 2000-2030 abatement in stabilization scenarios (Rose et al., 2008)
  - Potential cost-containment role in U.S. cap-and-trade proposals

    e.g., ~50 $GtCO_2eq$ cumulative ag & forest mitigation to 2050 (EPA, 2008)
- Engineering or "bottom-up" abatement cost analyses provide essential estimates of the costs of abatement technologies
- Top-down modeling (i.e., economy-wide, integrated assessment, global sectoral models) incorporates the bottom-up information via abatement supply curves or calibration
- However, bottom-up analyses generally evaluate individual technologies and ignore interactions between technologies
- Crop process models provide an opportunity for evaluating these interactions and potentially improving agricultural mitigation supply estimates

Offsets in U.S. Climate Policy Analysis



Source: EPA's analysis of the Lieberman-Warner Climate Security Act of 2008 (S. 2191), http://www.epa.gov/climatechange/economics/economicanalyses.html

Challenges

- Spatial and temporal heterogeneity in biophysical and management conditions
- Multiple GHG fluxes and interactions between them
- Availability of region-specific cost data for mitigation options
- Estimation of regional adoption of mitigation options relative to baseline in response to incentives (e.g., carbon price)

Enhancing Abatement Cost Estimation

Biophysical Modeling

DNDC model for Asian rice systems

DAYCENT model for world croplands

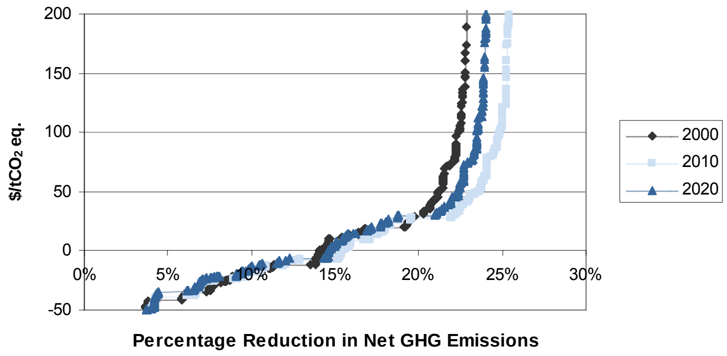
Literature sources for livestock options

Components

Biophysical
Δ GHGs
Δyields/productivity
Δ fertilizer inputs

Economic
IMPACT agricultural commodity and input prices (current and projected)
Δ labor
Δ capital costs
Input cost shares

Abatement cost curves for 2000, 2010 and 2020



Source: EPA, 2006

Break-Even Prices

- The break-even price for each mitigation option is calculated according to the equation below, which sets total benefits equal to total costs, and solves for the present-value, break-even price (P), expressed in 2000 US$/tCO2eq.
- $$\sum_{t=1}^{T}\left[\frac{(P \bullet ER)+R}{(1+DR)^{t}}\right]=CC+\sum_{t=1}^{T}\left[\frac{(RC)}{(1+DR)^{t}}\right]$$
- Where
  - ER is the absolute net GHG emission reduction
  - R is the revenue effect as a result of the mitigation option (e.g., yield changes, electricity generation)
  - CC is capital costs for each option
  - RC includes recurring annual costs (scaled to different regions based on agricultural labor wages) and input costs such as fertilizers
  - T is the assumed useful life of capital equipment used for mitigation
  - DR is the discount rate, assumed to be 5 percent

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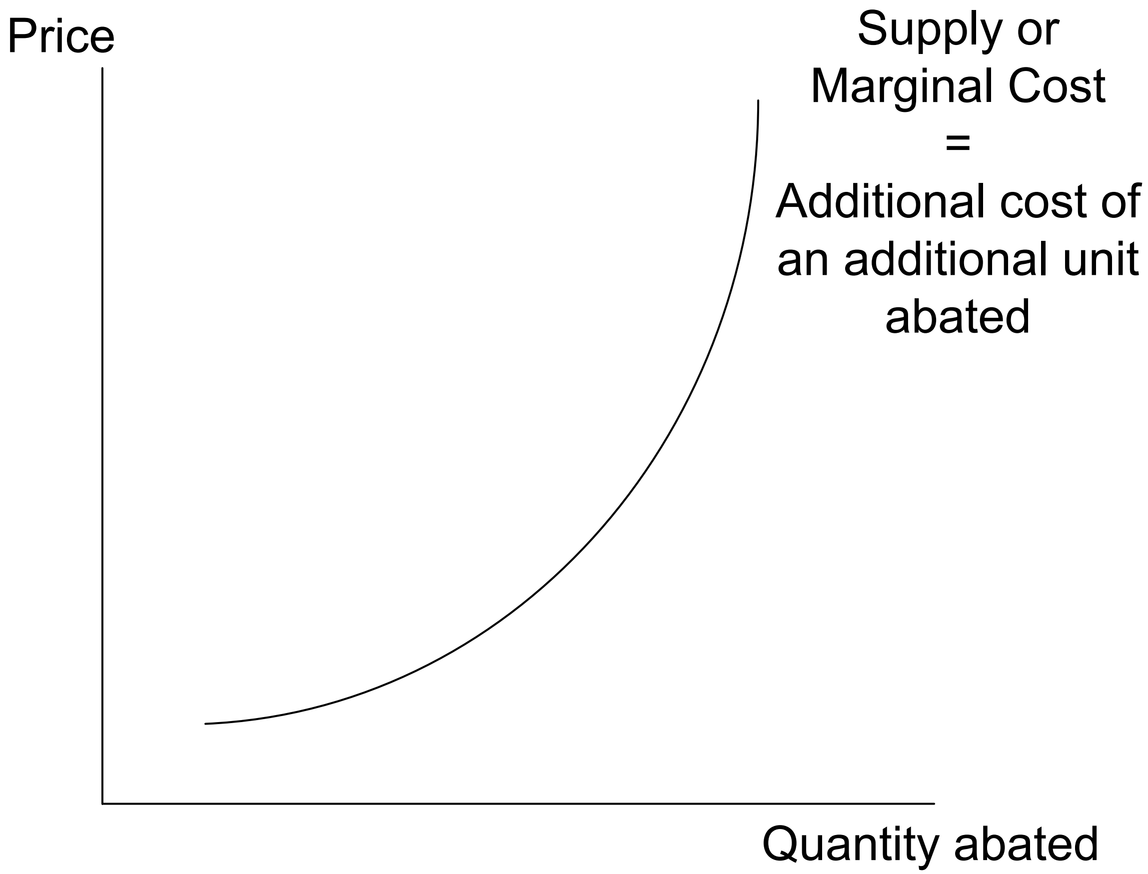
Conceptual Issues in Marginal Abatement Cost Curve Development



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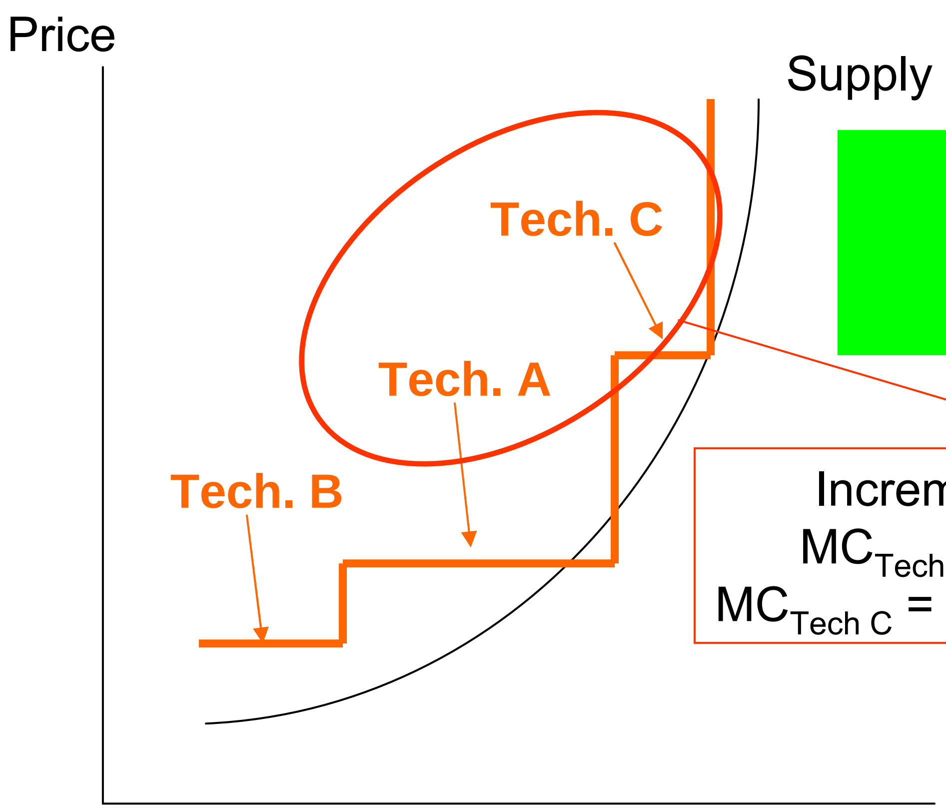
Development of MAC Curves Based on Least-Cost Ordering of Mitigation Options



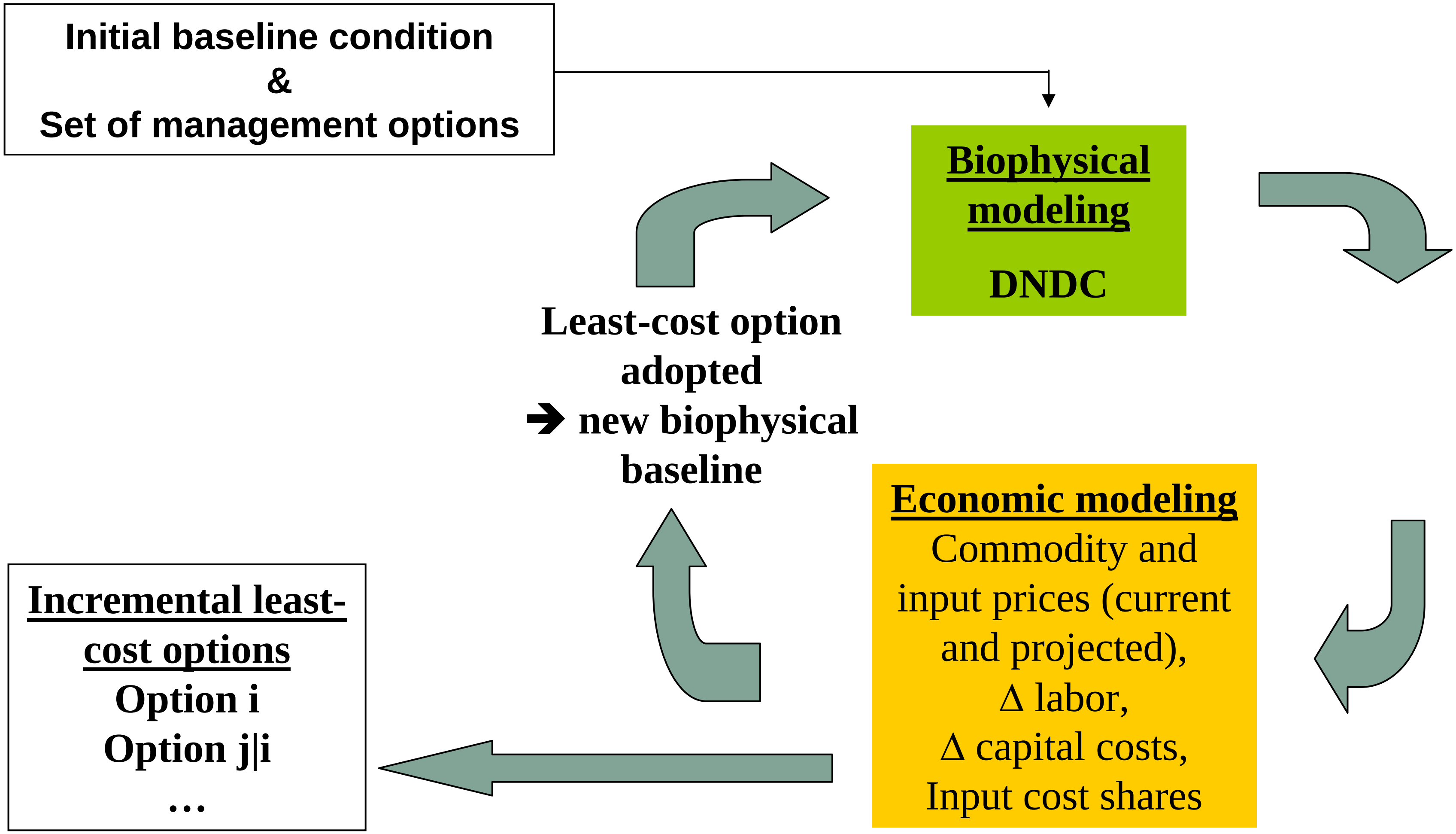
However, typically ignore interaction and compare MC(Tech A|base), MC(Tech B|base), MC(Tech C|base)

Incremental adoption implies:

$MC_{\text{Tech A}}$ = MC(Tech A|Tech B)

$MC_{\text{Tech C}}$ = MC(Tech C|Tech A,Tech B)

Overview of Methodology for Case Study of Rice Cultivation in China



Reference Case

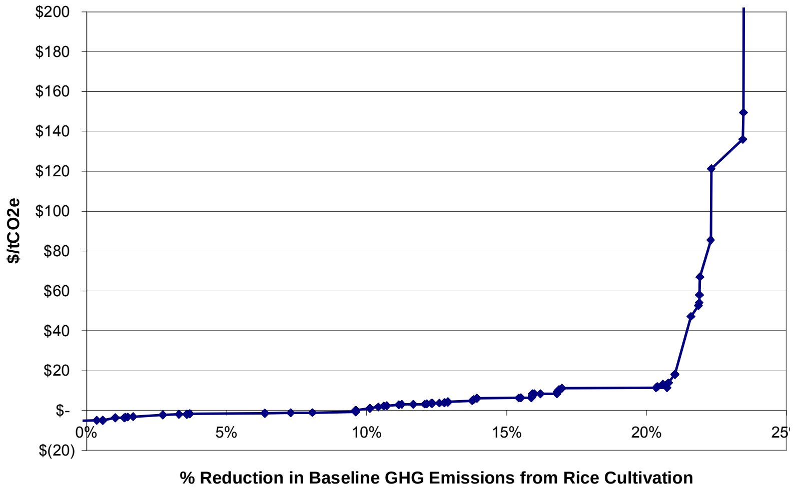
- Defined management practices consistent with our best estimate of typical management practices in 2000
  - Assumed that rice yields increased by 1% annually between 2000 to 2020
  - 80% of rice paddies in China were managed using mid-season drainage and 20% continuous flooding
  - Rate of aboveground crop residue incorporation increased by 5% annually from 15% in 2000 to 50% in 2008 and remained at 50% thereafter
  - Rice fertilizer application rate was 140 kg N/ha per season
  - Soil was tilled conventionally
  - No manure was applied
  - 1000 kg rice straw carbon/ha was amended at the beginning of the rice growing season each year

Rice Cultivation Mitigation Options

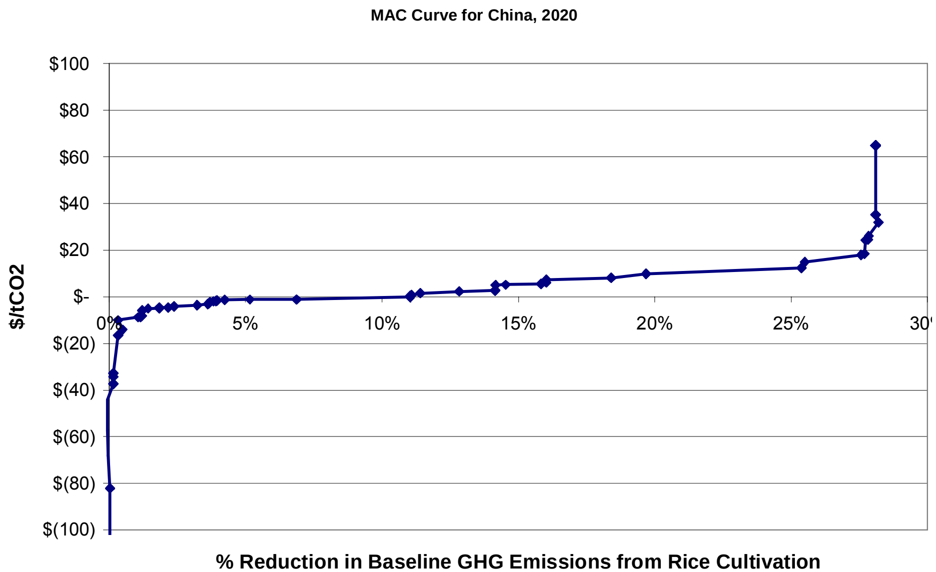
- Mid-season drainage - shift from 80% to 100% adoption of midseason drainage across China. Rice fields are dried three times within a growing season and the surface water layer is 5-10 cm while flooded
- Shallow flooding - water table fluctuating 5-10 cm above and below the soil surface
- Off-season addition of straw - rice straw amendment is applied two months before, rather than at the beginning of, the rice growing season, which reduces availability of dissolved organic carbon (DOC) released from the fresh straw to methanogens
- Switch to ammonium sulfate fertilizer - baseline fertilizer types, urea and ammonium bicarbonate, were replaced with ammonium sulfate; sulfate contributes to unfavorable conditions for methanogenic microbes
- Use slow-release fertilizer - nitrogen is slowly released from the coated or tablet fertilizer at a constant rate over a 30 day period following fertilizer application; increases N use efficiency and alters the relevant soil C and N dynamics
- Switch to upland rice production – not used because of major yield reductions

MAC Curves for Rice Cultivation Globally and for China

- Total global mitigation above 20% at about $10/tCO2eq in 2020
- Costs rise very rapidly after that point



Global MAC Curve, 2020 (EPA, 2006)



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Net GHG Effects of Conversion to Shallow Flooding in China, 2000-2020 (Li et al, 2006)

Waterbasin	Average Annual Reduction in Emissions	Proportion of National Area	Baseline (kg CO2eq/ha)	Average Annual Change (kg CO2eq/ha)	Average Annual Change (1000 tonnes CO2eq)	Proportion of National Reduction
Inland	52%	0.00	17,882	-9,213	-415	0.00
Haihe	58%	0.01	19,283	-11,248	-2,346	0.01
Songliao	46%	0.10	15,600	-7,116	-13,522	0.08
Huaihe	55%	0.13	23,113	-12,729	-30,546	0.18
Huanghe	58%	0.01	14,354	-8,349	-1,675	0.01
ZhuJiang	58%	0.17	43,436	-25,232	-78,540	0.46
Southeast	53%	0.08	33,614	-17,640	-26,681	0.16
Changjian	56%	0.48	3,374	-1,899	-16,825	0.10
Southwest	44%	0.02	7,625	-3,257	-996	0.01

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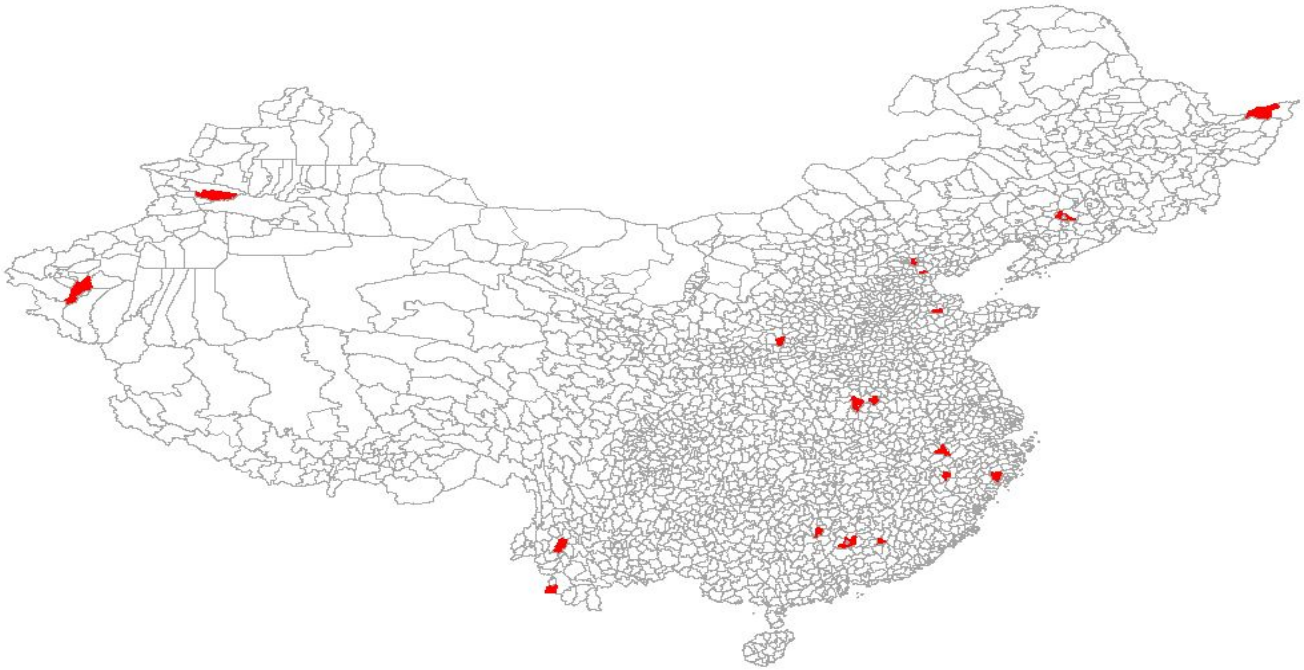
Accounting for Incremental Mitigation

- Issue:
  - How to combine cost/performance data for abatement technologies when they may not be mutually exclusive?
    - The biophysical responses (yields, GHG fluxes) of individual technologies are sensitive to existing conditions that are defined by previous management decisions
- Research question:
  - How important are incremental biophysical responses in estimating abatement supply?

Case Study: Rice Paddies in Selected Counties in China

- County selection
  - 9 water basins, 2 counties per basin
  - For each basin, selected counties at 25th and 75th percentile for county-level net GHG emissions/ha among counties with > 50% of average sown area in water basin
- 5 management options
  - Conversion to full mid-season drainage
  - Shallow flooding
  - Off-season straw amendments
  - Conversion to ammonium sulfate
  - Slow-release fertilizer
- Biophysical model: DNDC version 8.3
  - Process-based, soil bio-geochemical model w/ daily time step
  - Inputs: soil characteristics, rice area and systems, daily weather, management practices
    - Rice area based on remote sensing and Chinese surveys (Frolking et al. 2002)
    - Soil properties, management practices from latest Chinese surveys and published literature
    - Daily weather (from 1990) from NOAA
  - Outputs: CH_4, N_2O, SOC, yields, leached N, and water requirements per year over 20 year horizon

Counties Selected for this Analysis



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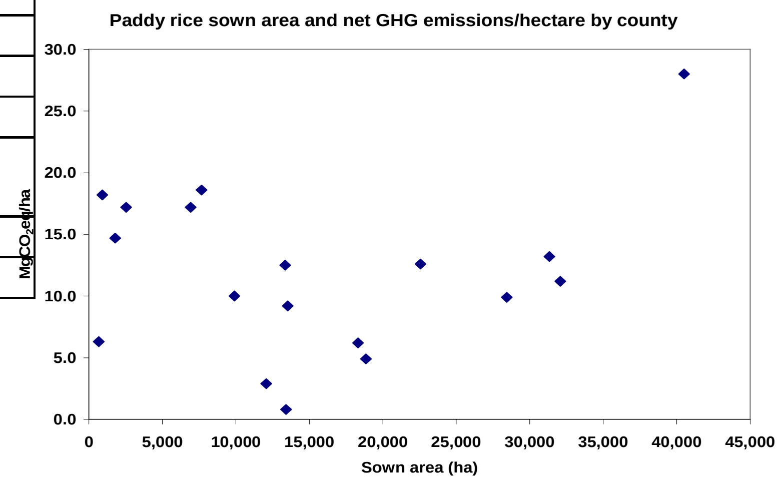
Distribution of Rice Area and Net GHG/ha by County

Table 1. Chinese Counties Selected for Incremental Marginal Abatement Cost Analysis

River Basin	County Name	Province Name	Sown Area (ha)	Net GWP (CO_2eq/ha)
Haihe	Tongxian	Beijing	6,925	17.2
Haihe	Beijiao	Tianjin	1,784	14.7
Songliao	Tieling	Liaoning	7,665	18.6
Songliao	Tongjiang	Heilongjiang	13,356	12.5
Huaihe	Xinyang	Henan	40,500	28.0
Huaihe	Xixian	Henan	31,334	13.2
Changjian	Guangfeng	Jianxi	32,080	11.2
Changjian	Lanshan	Hunan	18,850	4.9
ZhuJiang	Qujiang	Guangdong	28,441	9.9
ZhuJiang	Dingnan	Jiangxi	12,067	2.9
Southeast	Yongjia	Zhejiang	22,558	12.6
Southeast	Xiuning	Anhui	18,314	6.2
Huanghe	Gaoqing	Shandong	915	18.2
Huanghe	Hanchengshi	Shaanxi	13,526	9.2
Southwest	Menglian	Yunnan	9,896	10.0
Southwest	Fengqing	Yunnan	13,417	0.8
Inland	Shache	Xinjiang	2,530	17.2
Inland	Xingyuan	Xinjiang	670	6.3



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Alternatives for Creating MAC Curves Examined

- “Optimistic” – use as is (stack lowest to highest)
- “Conservative” – divide emissions space equally across options (stack)
- “Incremental” – select least-cost option, then estimate incremental responses of remaining options
- For all three alternatives, options that increase emissions are not included and rice production is held constant

Xinyang County - Changes in Emissions and Yields (Annual Averages Relative to Base)

Technology	dSOC $TgCO_2eq$	N_2O $TgCO_2eq$	CH_4 $TgCO_2eq$	Net GHG $TgCO_2eq$	Rice Yield kgC/ha/yr
Baseline	-0.123	0.335	1.016	1.228	2407
Slow-release fertilizer	-0.132	0.276	1.034	1.177	2544
Shallow flooding	-0.077	0.245	0.390	0.557	2702
Midseason drainage	-0.125	0.396	0.848	1.119	2468
Offseason straw	-0.119	0.332	0.895	1.108	2410
Sulfate fertilizer	-0.128	0.169	0.998	1.039	2345
Revised baseline (Slow-release fertilizer)	-0.132	0.276	1.034	1.177	2544
Shallow flooding	-0.082	0.255	0.398	0.571	2800
Midseason drainage	-0.136	0.319	0.868	1.051	2623
Offseason straw	-0.131	0.271	0.913	1.053	2541
Sulfate fertilizer	-0.132	0.147	0.956	0.971	2688

County ID 161703

Baseline Net GHG emissions 1.228 *TgCO2eq*

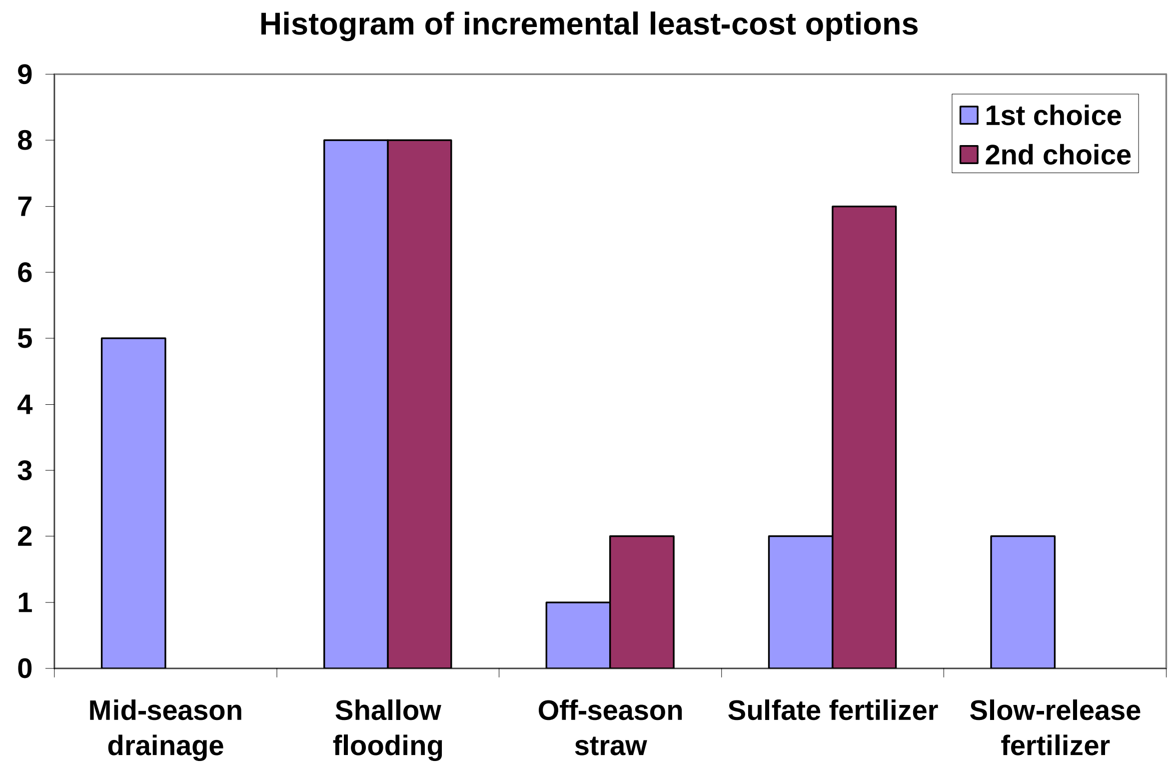
Technology ID	Total Reduction in GHG Emissions (TgCO2eq)	Break-Even Price ($/tCO2eq)	Percent reduction from baseline
Slow-release fertilizer	0.051	$ (12.05)	4%
Shallow flooding	0.671	$ (3.16)	55%
Midseason drainage	0.109	$ (1.57)	9%
Offseason straw	0.120	$ 3.64	10%
Sulfate fertilizer	0.189	$ 4.06	15%

Incremental Least-Cost Options

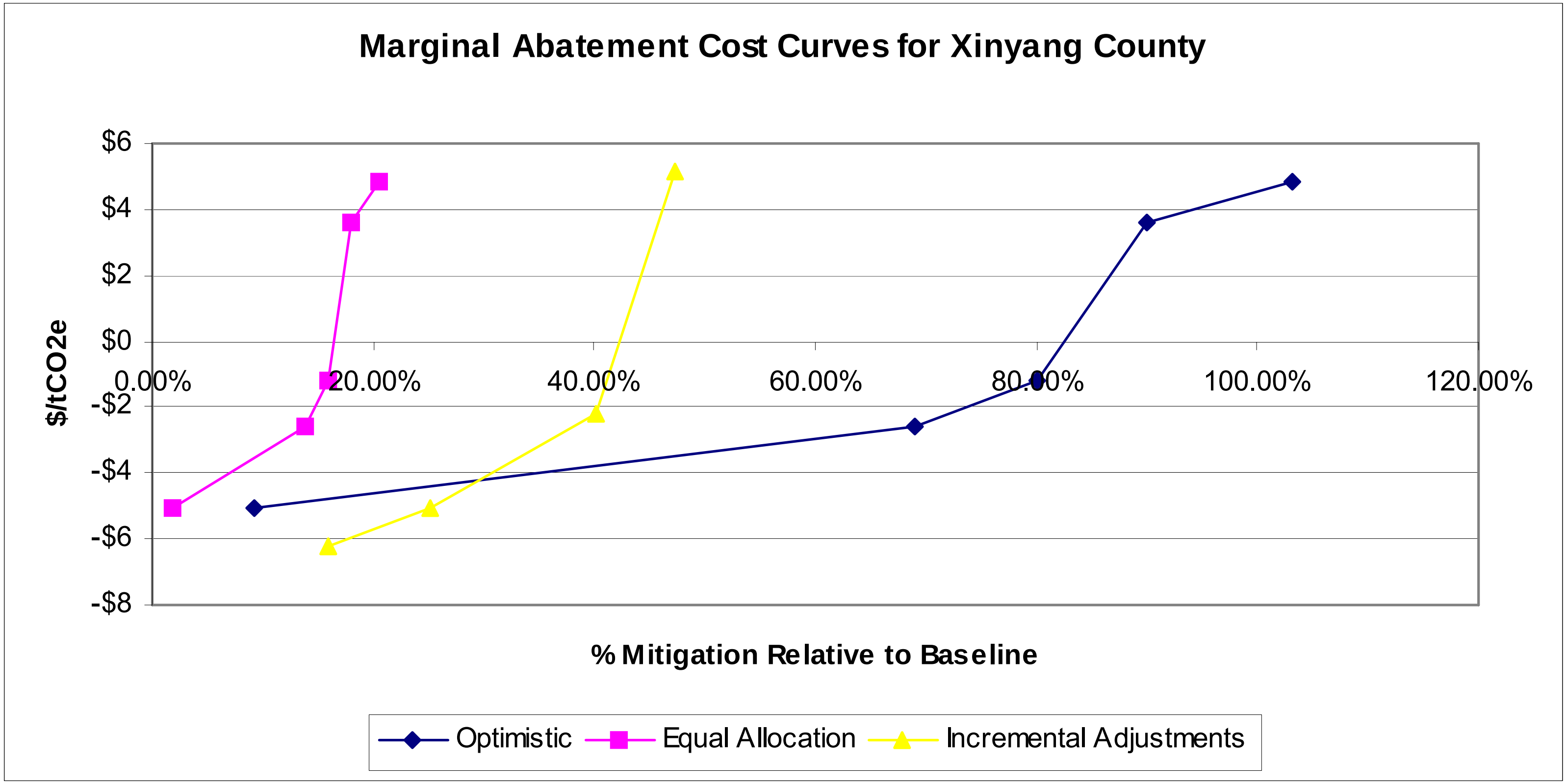
County	Initial least-cost option	2nd options: Incremental	2nd options: Non-incremental
Tongxian	Shallow flooding	Sulfate fertilizer	Sulfate fertilizer
Beijiao	Mid-season drainage	Shallow flooding	Shallow flooding
Tieling	Mid-season drainage	Shallow flooding	Sulfate fertilizer
Tongjiang	Sulfate fertilizer	Off-season straw	Shallow flooding
Yongjia	Shallow flooding	Sulfate fertilizer	Sulfate fertilizer
Xiuning	Shallow flooding	none	Sulfate fertilizer
Dingnan	Shallow flooding	Sulfate fertilizer	Sulfate fertilizer
Guangfeng	Slow-release fertilizer	Shallow flooding	Shallow flooding
Gaoqing	Mid-season drainage	Shallow flooding	Shallow flooding
Xixian	Shallow flooding	Sulfate fertilizer	Off-season straw
Xinyang	Slow-release fertilizer	Shallow flooding	Shallow flooding
Lanshan	Shallow flooding	Sulfate fertilizer	Mid-season drainage
Qujiang	Shallow flooding	Sulfate fertilizer	Mid-season drainage
Menglian	Off-season straw	Shallow flooding	Shallow flooding
Fengqing	Shallow flooding	Sulfate fertilizer	Mid-season drainage
Hanchengshi	Sulfate fertilizer	Off-season straw	Shallow flooding
Xingyuan	Mid-season drainage	Shallow flooding	Shallow flooding
Shache	Mid-season drainage	Shallow flooding	Shallow flooding

Even if the 2nd options are the same option, yield and GHG responses differ

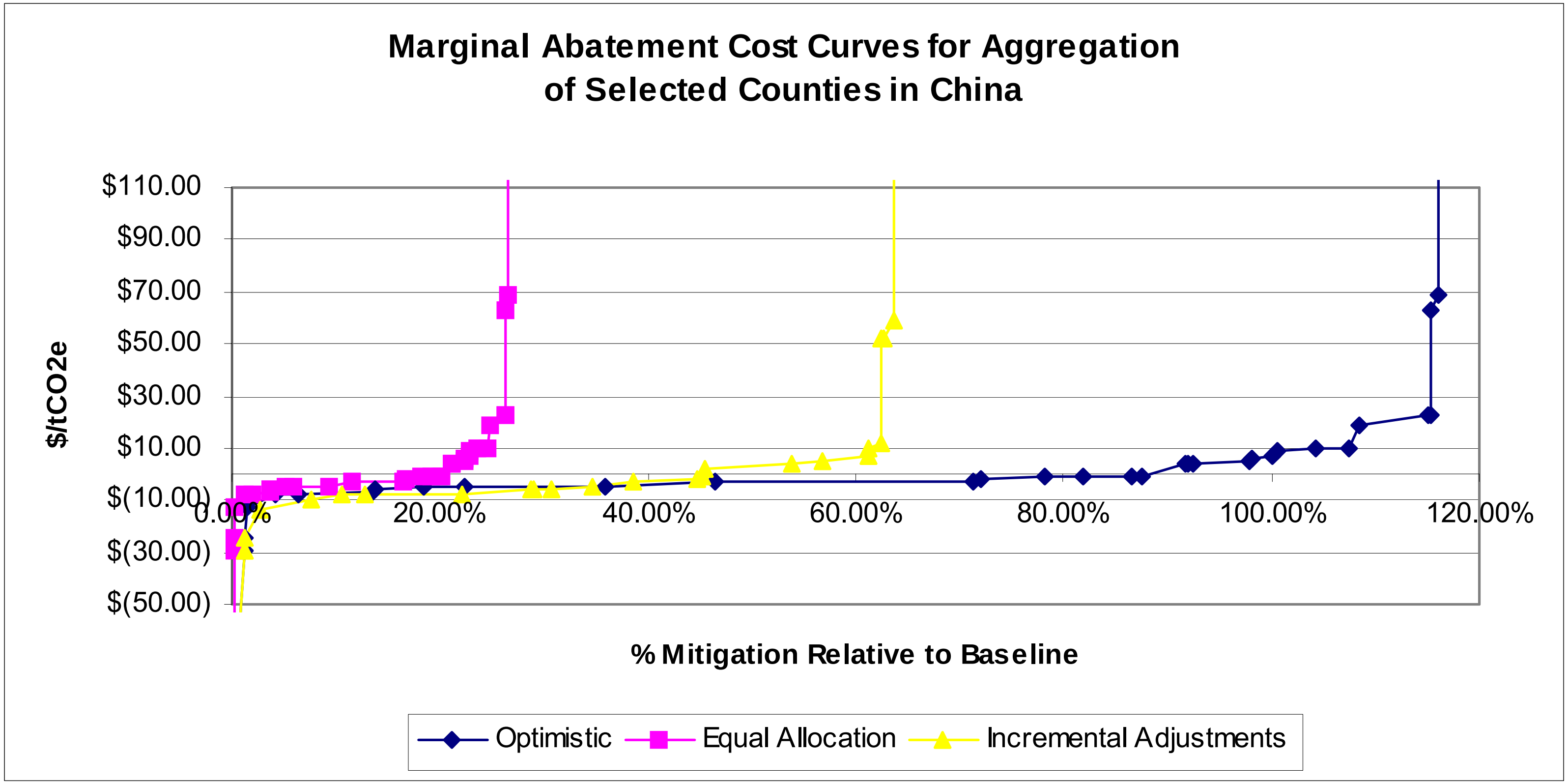
Heterogeneity in Ordering of Least-Cost Mitigation Options



Abatement Schedules – Xinyang County



Comparison of MAC Curves



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Initial Conclusions

- Incremental responses are important for estimating cropland abatement potential
  - Findings may have broad application (i.e., croplands of all types)
  - Initial results suggest that current estimates of economic mitigation potential may be underestimated for biophysical reasons
- Provides a rationale for efforts to integrate dynamic economic and terrestrial ecosystem models
  - Where the biophysical state can be redefined by economic as well as climate/atmospheric factors
- Some issues:
  - Adoption of combinations of options
  - Timing of incremental adoption
  - Variable costs – incremental adoption cost data limitations
  - Heterogeneity affect on potential (vs. weighted average regional response)
- Areas for future work
  - Additional sensitivity analysis
  - More mitigation options and combinations
  - Adoption of options by region
  - Market feedback
  - Impacts of climate change on agricultural conditions, GHG emissions, and mitigation potential