Risk-Return Trade-offs of Conservation Agriculture in Global South

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Prepared for Advanced CA course, Karnal, 18th Dec 2024

Outline

1. Concept of risk-return trade-offs

2. Key questions and analytical procedures for understanding risk-return trade-offs
   - **What CA practices maximize return at minimal downside risk?**
     - Modern portfolio theory (MPT): mean-variance (EV), conditional value at risk (CVaR)
     - Just-pope, moments production function
     - Stochastic dominance comparisons
     - Lab in the field risk experiments
   - **How much to pay for adoption risk (e.g., through insurance) bundled with payments for ecosystem services?**
     - Certainty equivalent and risk premium
   - **Where to place CA to maximize returns and minimize risks?**
     - Pareto frontier analysis: search algorithms, genetic algorithm
3. Farmer risk perceptions of conservation agriculture
4. Conclusion

Resources

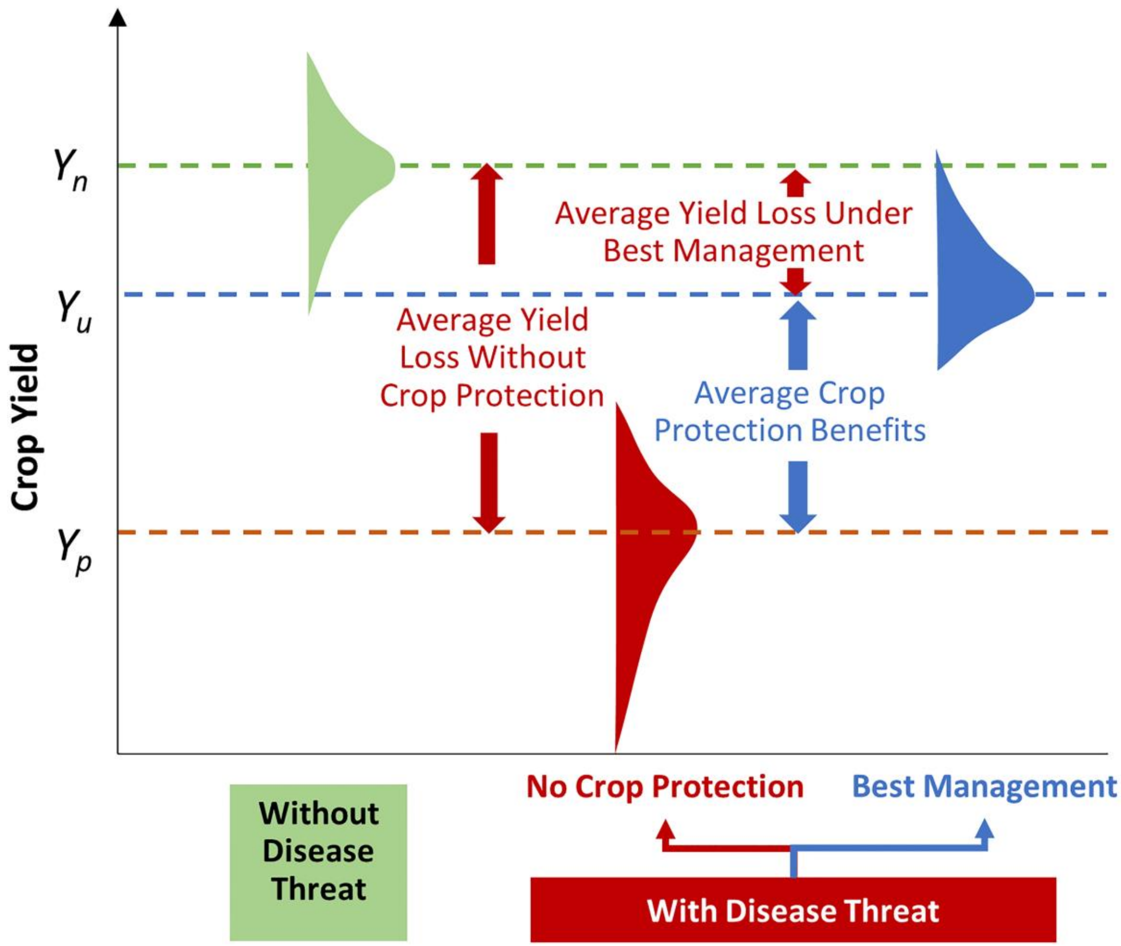
- Replication materials for the different methods
  - Online book in progress: https://maxwellmkondiwa.github.io/spatial_exante_sop_book/
- Slides and reference materials for 2022 lecture and this lecture
  - Clone the Github repository: https://github.com/MaxwellMkondiwa/Training_Materials

(1) Conceptual framework for risk-return trade-offs

Motivation

- When outcomes are uncertain, farmers may be more hesitant to adopt a practice, requiring additional compensation to induce adoption (Kurkalova et al., 2006;).
- Agricultural researchers usually use stability or inter-temporal variability (standard deviation, coefficient of variation) as a measure of risk.
- Good starting point. This talk will focus on how economists think about outcome-based risk.
- But need to think about
  - Downside risks, whole distribution not just mean/variance
  - Risk preferences of the farmer,
  - Farmer perceptions,
  - Portfolio choices and diversification,
  - Monetary cost of risk and
  - Shadow prices of ecosystem services.

Goal: Risk proofing agriculture with conservation agriculture

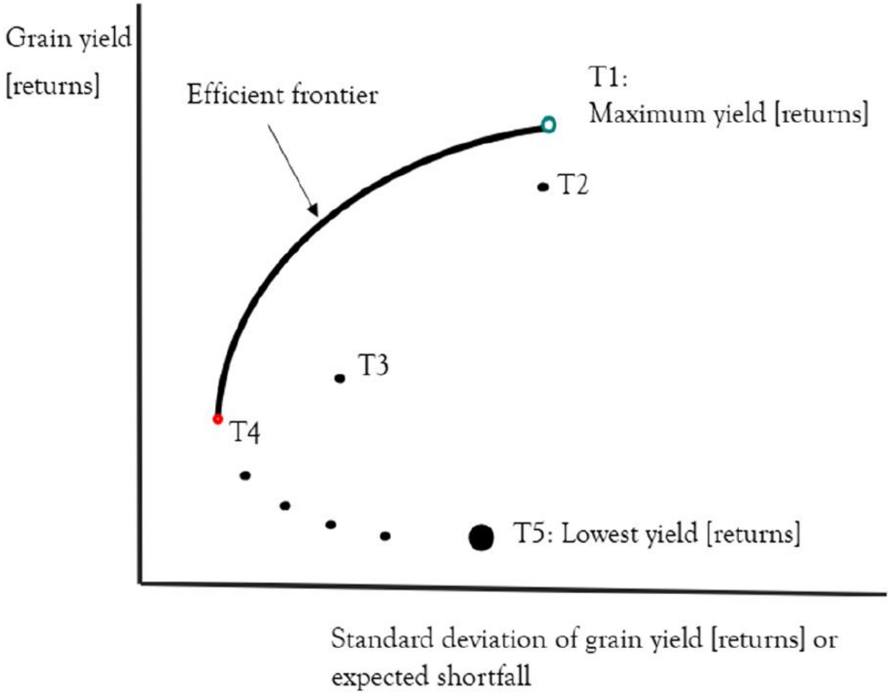


Chai et al (2022)

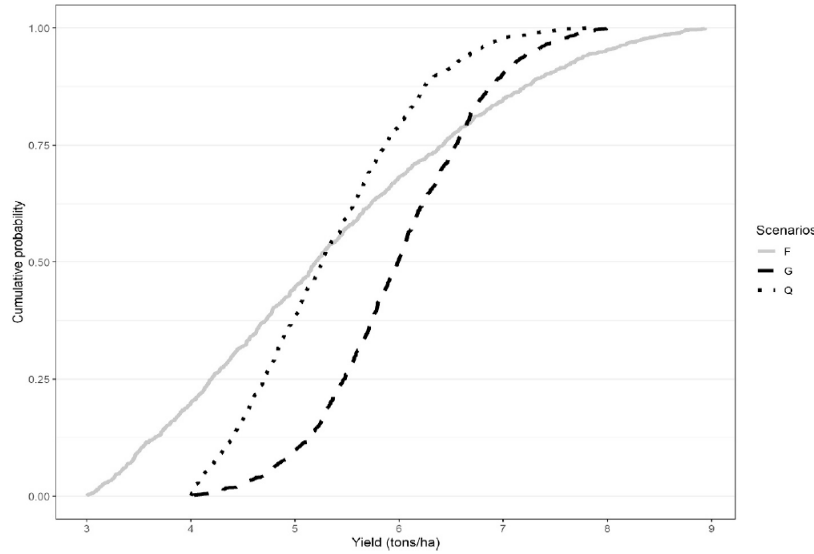
Without Drought Threat

With Drought Threat

(a) Mean-variance (EV) or mean-conditional value at risk (CVaR)



(b) Stochastic dominance analysis



[ypothetical stochastic dominance assessment.

Stochastic efficiency with respect to a function (certainty equivalence and risk premium)

- Identifies and orders utility efficient alternatives in terms of certainty equivalents (CE) for a risk preference.
- The CE of a risky alternative (in this study the type of tillage system) is the amount of money at which the decision maker is indifferent between the certain dollar value and the risky alternative.
- If $CE_{CA} > CE_{Conventional}$ then CA is beneficial for both return and risk.
- Assume, farmers want more money to less

Stochastic efficiency with respect to a function (SERF) functional forms

- Power
- Negative exponential
- Quadratic
- Log-log

- Example: power utility function: CRRA, DARA

$$U(w) = \frac{w^{(1-r_r(w))}}{1-r_r(w)}$$

$$CE(w, r_r) = U^{-1}(w, r)$$

R: risk aversion parameter (0.5, 4): Anderson and Dillon (1992).

0.5= Hardly risk averse, 4=extremely risk averse, 0=risk neutral

- Most studies divide this by farmers income

- Risk premium=EV-CE
- RP (A,B,r)=CE(A, r)-CE(B,r)
- RP for a risk-averse decision maker **reflects the minimum amount ($ ha−1 for the tillage systems) that would have to be paid to a decision maker to justify a switch from alternative A to B**

Discussion questions

- Identify one CA variant being advocated in area of interest

1. How do we incorporate **risk and uncertainty** in the current advisories?
2. What are **the sources of risk associated with that CA variant** (either risk mitigation or riskiness)?
3. Does consideration of **farmer risk preferences (some being risk lovers, risk neutral or risk averse)** change what we would recommend?
4. How do we communicate **uncertainty of our outcomes of CA advisories**? Should we?

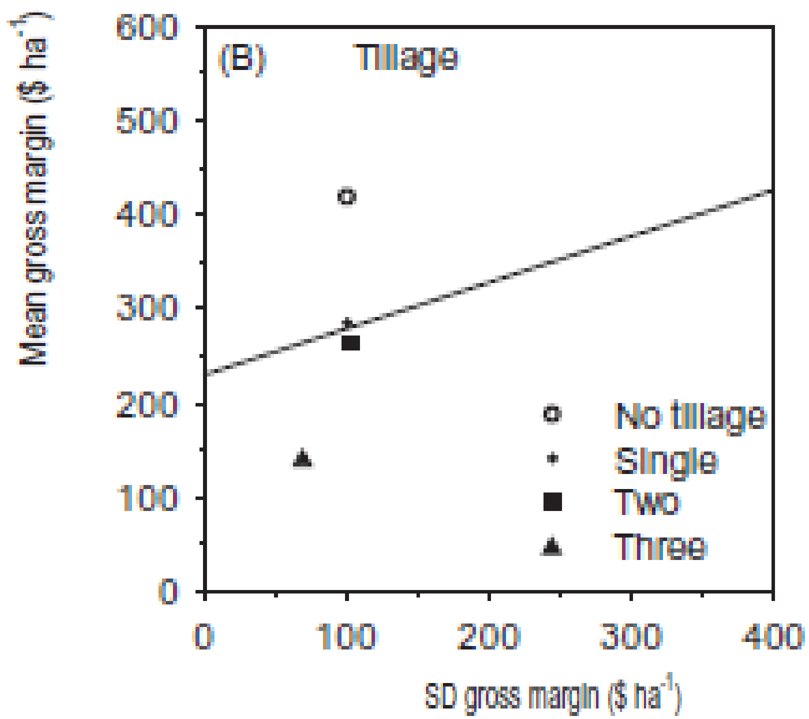
(2) Key questions and analytical procedures

2.1. What CA practices maximize returns at minimal risk?

- Analytical procedures
  - ✓ Modern portfolio theory (MPT): mean-variance, conditional value at risk
  - ✓ Stochastic dominance comparisons
  - ✓ Just-pope, moments production function
- Examples
  - **India, New Delhi:** Risk-return tradeoffs paper-Nayak, **Mkondiwa** et al 2024. **European Journal of Agronomy**
  - **Mozambique:** Kidane et al (2019) Agronomy Journal
  - **Malawi:** Ngwira et al (2013) Experimental Agriculture
  - **USA: Williams et al (2012)**

Morocco example: Visual mean-variance scatter plot

- Used 1:2 ratio between gross margin and standard deviation as the line of indifference frontier following on Barah et al 1981; Peake et al 2016



Agricultural Systems 185 (2020) 102946

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

ELSEVIER

Explaining yield and gross margin gaps for sustainable intensification of the wheat-based systems in a Mediterranean climate

Mina Devkota[a,*], Yigezu Atnafe Yigezu[b]

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EV and CVaR Quadratic programming: Nayak, Mkondiwa et al 2024 European Journal of Agronomy

European Journal of Agronomy 162 (2025) 127436

Contents lists available at ScienceDirect

European Journal of Agronomy

journal homepage: www.elsevier.com/locate/eja

Risk-return trade-offs in diversified cropping systems under conservation agriculture: Evidence from a 14-year long-term field experiment in north-western India

Hari Sankar Nayak [a,b], Maxwell Mkondiwa [c], Kiranmoy Patra [a], Ayan Sarkar [a], K. Srikanth Reddy [a], Pramod Kumar [a], Sneha Bharadwaj [d], Rajbir Singh [e], Chiter Mal Parihar [a,*]

[a] *ICAR-Indian Agricultural Research Institute (IARI), New Delhi, India*
[b] *School of Integrative Plant Science, Cornell University, Ithaca, NY, USA*
[c] *International Maize and Wheat Improvement Center (CIMMYT), New Delhi, India*
[d] *ICAR-Indian Agricultural Research Institute (IARI), Assam, India*
[e] *Indian Council of Agricultural Research (ICAR), New Delhi, India*

R code for methodology: https://github.com/EiA2030-ex-ante/Risk_modern_portfolio_theory_EV_model

IARI New Delhi LTE, India

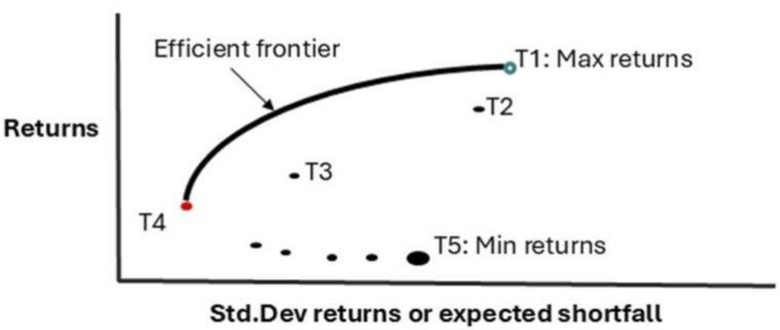
Risk-return trade-offs in diversified cropping systems under conservation agriculture

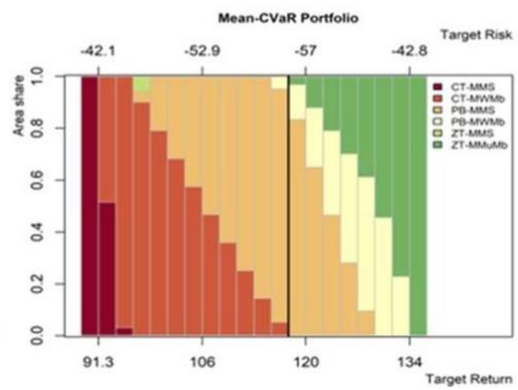
Motivation: Integrate downside risk in analyzing long term experiments

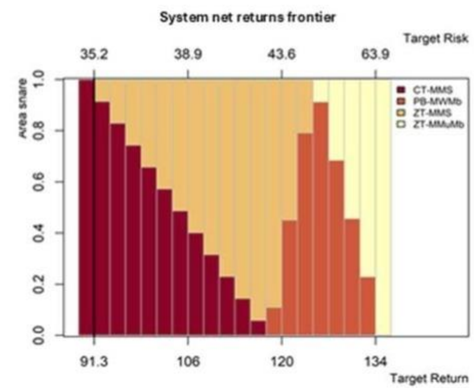
Model input: 14-year long field experiment data in north-western India [2008-2022]

Model: Modern portfolio theory (MPT) optimization algorithms: Mean-variance (EV) and Conditional Value at Risk (CVaR) analysis

Model output: Optimal portfolio of treatments



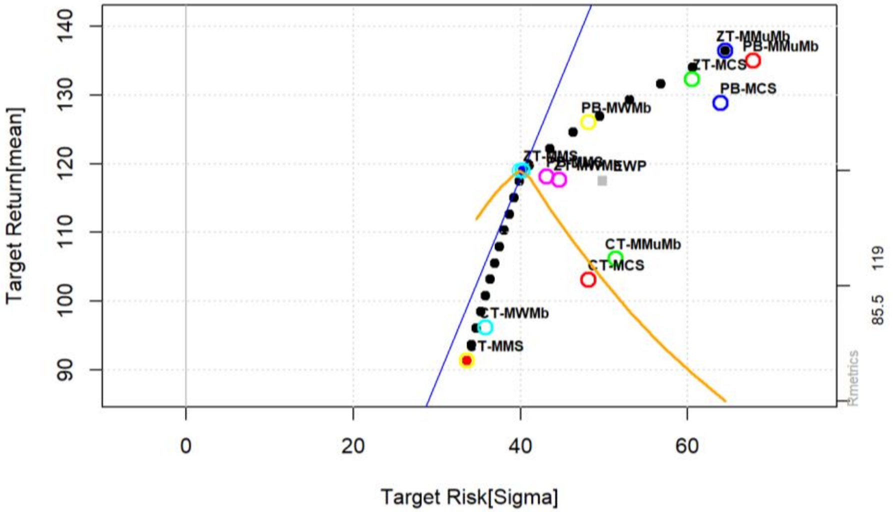


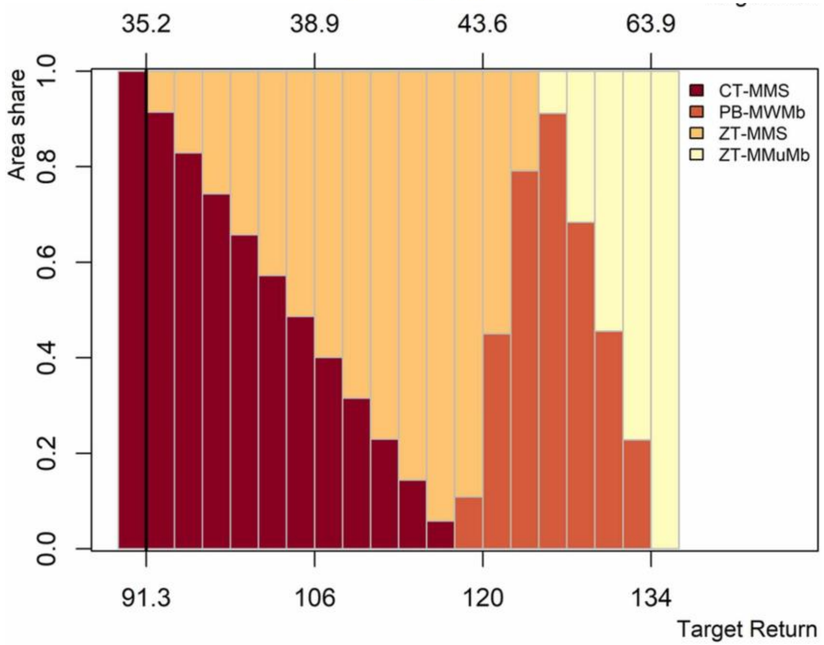


Main result

- Highest profit for risk neutral farmer:
  - ZT: Maize: Mustard: Mungbean

- **CT-MMS:** On frontier for very risk averse farmers but mostly if in combination with ZT-MMS.





Stochastic dominance: Mozambique: Kidane et al 2019. Agronomy journal

Published online March 14, 2019
ON-FARM RESEARCH

Conservation Agriculture and Maize Production Risk: The Case of Mozambique Smallholders

Simon M. Kidane, Dayton M. Lambert,* Neal S. Eash, Roland K. Roberts, and Christian Thierfelder

Variation dependent on altitude. At higher elevations, both high returns and low risk. Not clear at lower elevations.

Table 3. Komolgorov-Smirnoff two-sample comparison of net returns for conventional, basin and direct seeding technologies, Mozambique, 2008–2011.†

Technology	D-statistic‡ (net returns)	D-statistic (maize yield)	Stochastic dominance
Combined			
Conventional vs. basins	0.07*	0.10**	No dominance
Conventional vs. jab planting	0.12***	0.13***	No dominance
Basins vs. jab planting	0.06	0.05	Direct seeding, SDSD
Altitude £350 m			
Conventional vs. basins	0.07	0.08	No dominance
Conventional vs. jab planting	0.09	0.08	No dominance
Basins vs. jab planting	0.05	0.07	No dominance
Altitude: 350–800 m			
Conventional vs. basins	0.13*	0.10	No dominance
Conventional vs. jab planting	0.13*	0.15**	Direct seeding, FDSD and SDSD§
Basins vs. jab planting	0.08	0.07	No dominance
Altitude >800 m			
Conventional vs. basins	0.13	0.24***	No dominance
Conventional vs. jab planting	0.19**	0.26***	No dominance
Basins vs. jab planting	0.10	0.06	No dominance

*,**, *** significant 0.10, 0.05, and 0.001 levels, respectively.

† Based on cumulative distributions of Fig. 1.

‡ Distance statistic, Kolmogorov-Smirnoff (KS) test of the equality between empirical distributions, .

§ FDSD, first degree stochastic dominant; SDSD, second degree stochastic dominant.

Komolgorov-Smirnoff test of first order stochastic dominance

CIMMYT CGIAR

Just-Pope and Moments production function approach

- Methods are mostly relying on long-term or medium-term experimental data.
- The treatments are set for testing and there is not much room to test for complementarities and substitution.

- Just-Pope production function and moments approach does that
  - You estimate crop response function using OLS. This is the **mean model.**
  - The take square of the error terms and regress on same variables. This is the **variance model** [for risk both upside and downside]
  - You can take **third power:** this is the **skewness model** [for downside risks]
  - You can take **fourth power**: this is the **kurtosis model**

- **R code and data for an example are here: https://github.com/EiA2030-ex-ante/SpatialParametricProduction_Risk_Model**

CA and climate resilience in Zimbabwe


Journal of Environmental Economics and Management 93 (2019) 148–169

Contents lists available at ScienceDirect

Journal of Environmental Economics and Management

journal homepage: www.elsevier.com/locate/jeem

Conservation agriculture and climate resilience☆

Jeffrey D. Michler[a,*], Kathy Baylis[b], Mary Arends-Kuenning[b], Kizito Mazvimavi[c]

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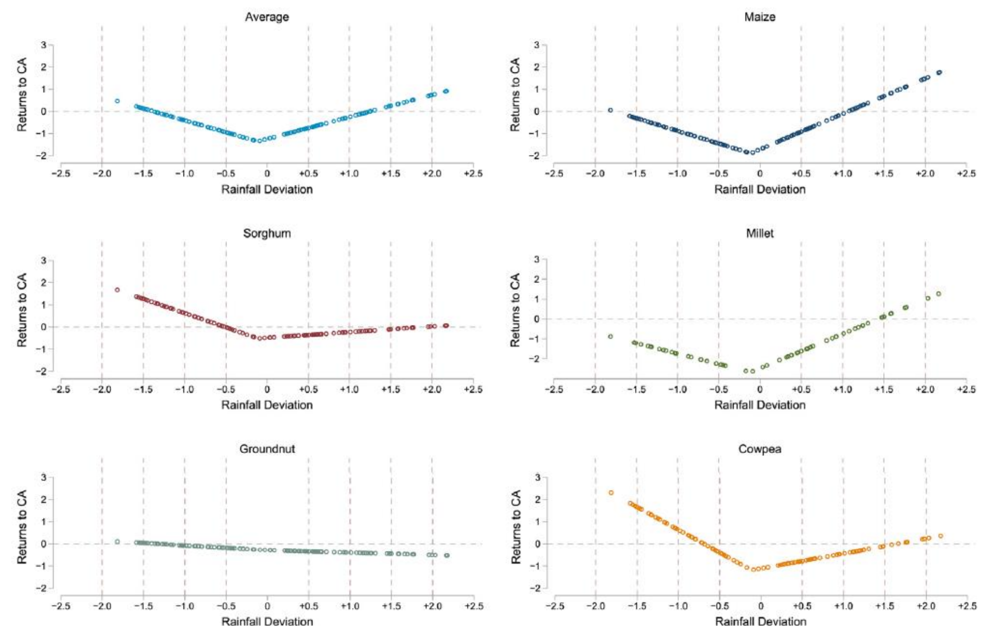
[b] Dept. of Agricultural and Consumer Economics, University of Illinois, Urbana, USA
[c] International Crops Research Institute for the Semi-Arid Tropics, Bulawayo, Zimbabwe



Note: Figure displays the predicted returns to CA averaged over all crops and also by crop. Returns are calculated using the coefficients from column (3) in Table 8. By crop, we multiple the coefficient on the CA × rainfall shortage by realized shortages and multiple the coefficient on the CA × rainfall surplus by realized surpluses. We then sum these values along with the coefficient on the CA term. For the average return we take a weighted average of the crop specific returns where the weights are the number of observations for each crop in the data. The x-axis marks the realizations of rainfall surpluses and shortages where shortages are to the left of zero. Dots represent individual predicted returns where a lower density of dots represents fewer observations, and thus less confidence. Vertical lines are drawn at ± half standard deviation intervals from the mean, which is 0.062.

Fig. 5. Predicted returns to CA by crop.

- CA beneficial in low or very high rainfall years
- In normal years, the additional returns were either none or less

Lab-in-the-field experiment
Campbell et al 2021: USA

Figure 1
Lottery choice question used to elicit producer risk preferences.

Q31. Indicate if you would or would not adopt *each* of the following technologies:

Farm Technology	---------IMPACTS ON YOUR FARM INCOME--------- *ADOPT* the technology, and you have a 50/50 chance of: *DECREASING* your farm income by:		*INCREASING* your farm income by:	*DO NOT ADOPT*, and your farm income is:	Would you adopt this technology? (Please check one box in each row) Yes, I would adopt	No, I would not adopt
A	-10%	or	+20%	Unchanged	☐	☐
B	-20%	or	+40%	Unchanged	☐	☐
C	-30%	or	+60%	Unchanged	☐	☐
D	-40%	or	+80%	Unchanged	☐	☐
E	-50%	or	+100%	Unchanged	☐	☐
F	-60%	or	+120%	Unchanged	☐	☐

Table 4
Parameter estimates and significant marginal effects for the probit models.

Parameters	Cover crop adoption probit (n = 168) Parameter estimates	Marginal effects	No-till adoption probit (n = 160) Parameter estimates	Marginal effects
Intercept	0.005 (0.996)	–	0.4404 (1.222)	–
C_{CC}	0.0035*** (0.0065)	0.009***	–	–
C_{NT}	–	–	0.0035 (0.244)	–
risk	−0.0535 (0.057)	–	−0.1532* (0.0812)	−0.0323*
corn	−0.0065 (0.008)	–	−0.0007 (0.007)	–
cotton	−0.0013 (0.009)	–	−0.0009 (0.009)	–
beans	−0.0007 (0.007)	–	0.0066 (0.007)	–
ha	−0.0004 (0.011)	–	0.0345 (0.025)	–
weeds	−0.1087 (0.345)	–	−0.3685 (0.437)	–
age	0.002 (0.011)		0.0011 (0.013)	–
edu	0.025 (0.268)		−0.053 (0.364)	–
income	−0.097 (0.128)		0.399* (0.236)	0.084*
Likelihood ratio	<0.001		<0.001	
McFadden R^2	0.185		0.123	
Correctly predicted	0.51		0.65	

*, **, and *** are significant at the 0.10, 0.05, and 0.01 levels, respectively.

Received: 13 September 2022 | Revised: 8 June 2023 | Accepted: 16 August 2023
DOI: 10.1111/agec.12797
AGRICULTURAL ECONOMICS The Journal of the International Association of Agricultural Economists
WILEY
ORIGINAL ARTICLE

Increasing the adoption of conservation agriculture: A framed field experiment in Northern Ghana

Kate Ambler[1] | Alan de Brauw[1] | Mike Murphy[1,2]

2.2. How much to pay for risk?

Risk premium

Agricultural Systems 218 (2024) 104014

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Agricultural Systems

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Risk-based evaluations of competing agronomic climate adaptation strategies: The case of rice planting strategies in the indo-Gangetic Plains

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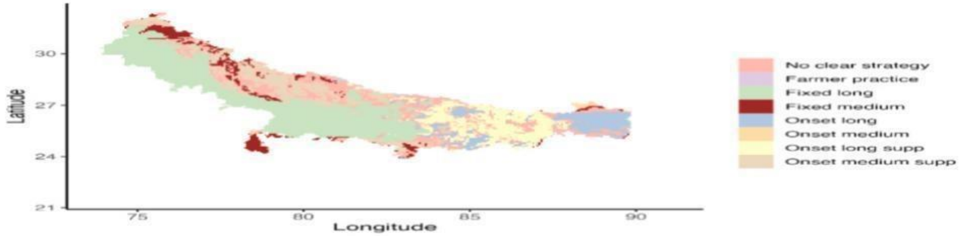
[d] College of Agriculture and Life Sciences, Cornell University, Ithaca, NY, United States of America

R code: https://github.com/EiA2030-ex-ante/WTP_Bounds_SOSD_Risk_Model

Risk-based evaluations of competing agronomic climate adaptation strategies: The case of rice planting strategies in the Indo Gangetic Plains

Motivation	Incorporate **climatic risk and farmer risk aversion** considerations in making scenario recommendations from crop growth simulation models
Research question	What are the spatially differentiated **rice-wheat system level optimal (profit maximizing) strategies** for sowing rice under climatic risk such that even a **risk averse farmer finds it beneficial**?
Model input	APSIM spatially gridded crop model results, Interpolated irrigation costs and output prices
Model algorithm	Link expected utility theory risk aversion conditions to second order stochastic dominance (SOSD) and grid search algorithm

Model output:
Optimal rice sowing strategy for a risk-averse farmer under climatic risk



Mozambique: Lalani et al (2017). Ecological Economics

B. Lalani et al. / Ecological Economics 141 (2017) 144–153

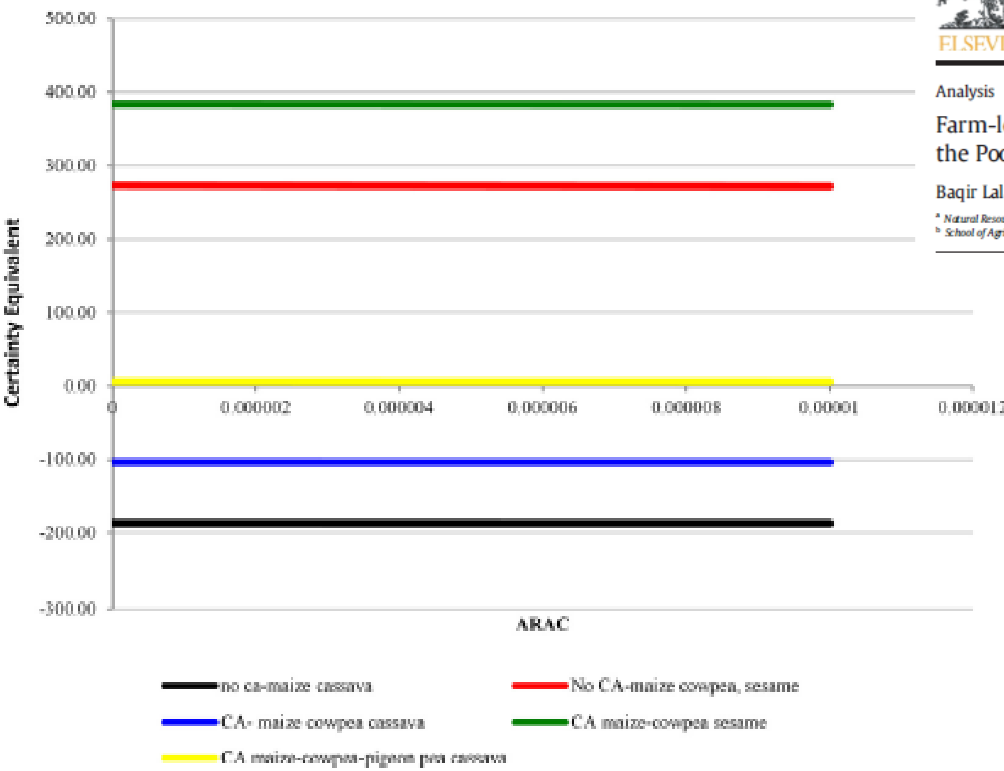
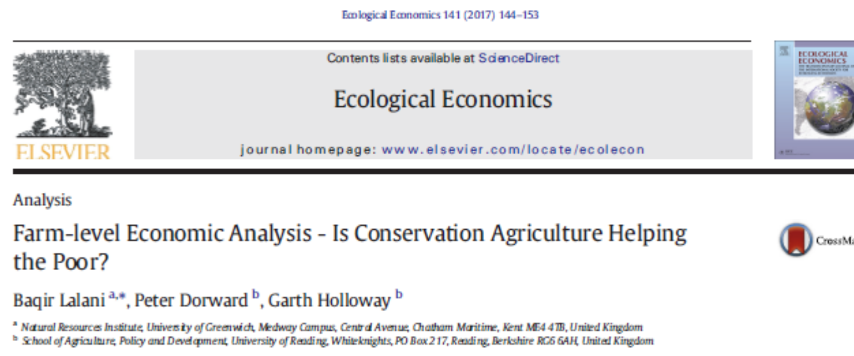


Fig. 1. Certainty equivalents (CE's) in USD for the most frequent crop mixes used by the poorest farmers under different risk tolerance levels.



Ecological Economics 141 (2017) 144–153

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

Analysis

Farm-level Economic Analysis - Is Conservation Agriculture Helping the Poor?

Baqir Lalani [a,*], Peter Dorward [b], Garth Holloway [b]

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[b] School of Agriculture, Policy and Development, University of Reading, Whiteknights, PO Box 217, Reading, Berkshire RG6 6AH, United Kingdom

Malawi

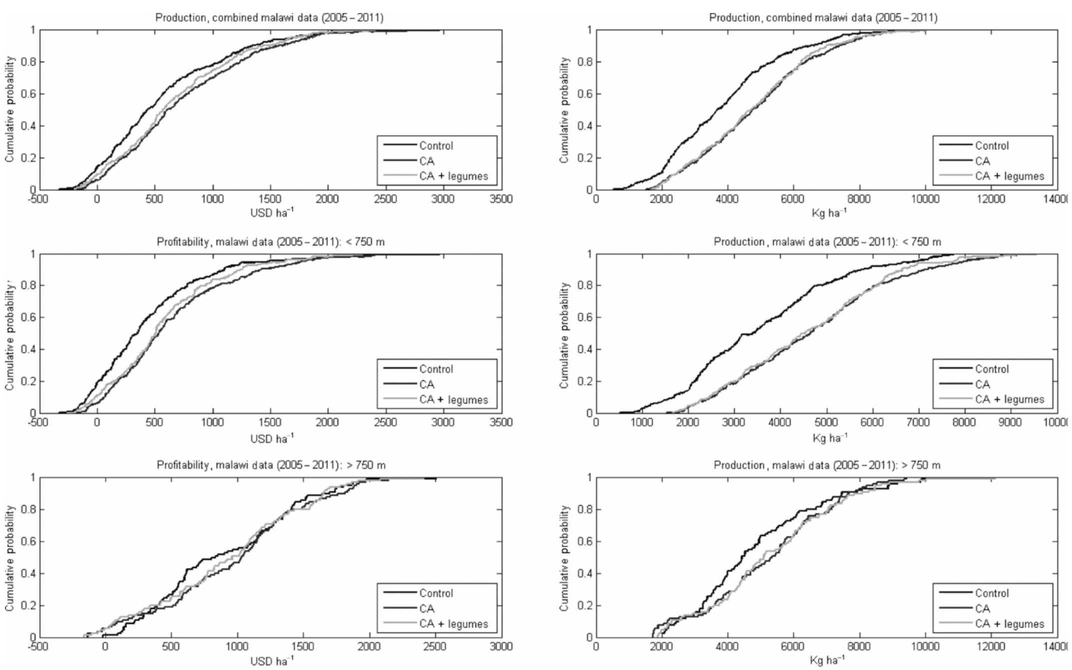
Ngwira et al 2013. Experimental Agriculture

- **Stochastic dominance**
- **Mean-variance analysis**
- **Certainty equivalents**

Expl Agric. (2013), volume 49 (4), pp. 483–503 © *Cambridge University Press 2013*
doi:10.1017/S0014479713000306

RISK AND MAIZE-BASED CROPPING SYSTEMS FOR SMALLHOLDER MALAWI FARMERS USING CONSERVATION AGRICULTURE TECHNOLOGIES

By A. R. NGWIRA†‡, C. THIERFELDER§, N. EASH¶ *and* D. M. LAMBERT††



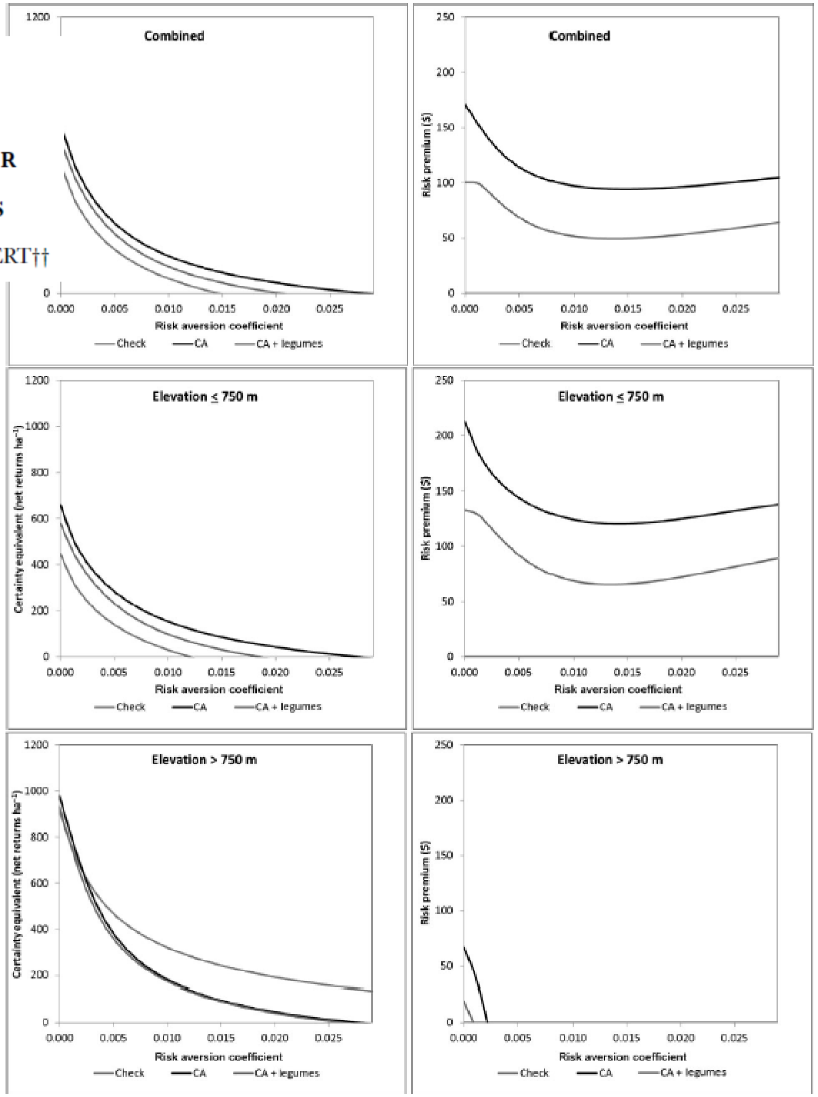
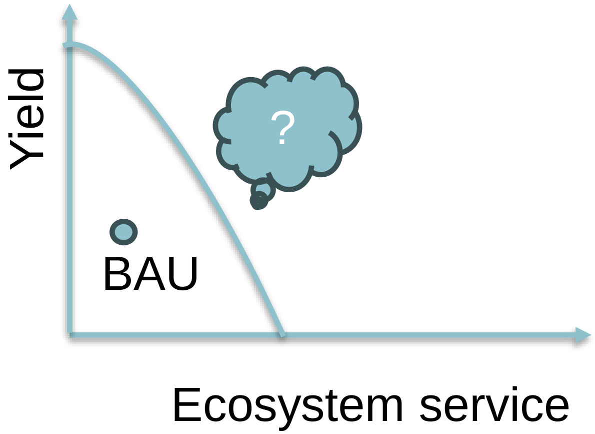


Figure 3. Certainty equivalents (2010 US$ ha^{-1}) and confidence premium associated with each technology.

2.3. Where to put CA? On-going research

- Spatial landscape optimization for **risk-return-ecosystem tradeoffs**
- Risk-return-ecosystem trade-offs and shadow price of GHG
- Time inconsistency and dynamic conditional value at risk of CA
- Economic surplus and risk assessment of CA



3. Impact of risk on adoption

Risk-aversion and adoption of CA practices in Zambia (Simutowe 2024)

Risk measured using
Likert scale questions

Table 3
Covariates influencing the extent of adoption for different CA practices.

	(1) Basins	(2) Ripping	(3) MT	(4) MT & rotation	(5) MT & mulch
Risk averse (1 = yes)	−0.028***	0.002	−0.035	−0.006	−0.032*
	(-2.625)	(0.054)	(-0.997)	(-0.470)	(-1.645)
Impatient (1 = yes)	0.031	−0.083**	−0.051**	−0.029**	−0.014
	(1.233)	(-2.495)	(-2.135)	(-1.998)	(-0.804)
Access to extension services (1 = yes)	0.001	0.127***	0.114***	0.043**	0.112***
	(0.048)	(3.769)	(3.788)	(2.334)	(5.158)
Age of household head	0.013	0.131	0.134	0.097*	0.177**
	(0.214)	(1.248)	(1.585)	(1.736)	(2.420)
Education of household head	0.025	0.140***	0.125***	0.071***	0.022
	(1.639)	(4.457)	(3.772)	(2.832)	(0.971)
Female household head (1 = yes)	0.007	−0.043	−0.049*	−0.006	−0.010
	(0.411)	(-1.222)	(-1.905)	(-0.308)	(-0.522)
Household size	0.018	0.019	0.019	0.023	0.042
	(1.224)	(0.501)	(0.472)	(1.358)	(1.438)
Farm size	−1.035	1.365	1.219	0.003	0.833
	(-0.791)	(1.195)	(1.000)	(0.007)	(0.843)
Used weather information (1 = yes)	0.001	0.013	−0.006	0.044***	0.035*
	(0.128)	(0.499)	(-0.239)	(3.196)	(1.690)
Member of cooperative (1 = yes)	0.000	0.044	0.046*	0.024	−0.014
	(0.030)	(1.374)	(1.788)	(1.446)	(-0.591)
Observations	1324	1324	1324	1324	1324

Note: z-statistics in parentheses ***p < 0.01, **p < 0.05, *p < 0.1. Standard errors clustered at camp/ward level.

9

Table 4
Covariates influencing the adoption intensity of different CA practices.

	(1) Basins	(2) Ripping	(3) MT	(4) MT & rotation	(5) MT & mulch
Risk averse (1 = yes)	−0.018***	0.024	−0.057	−0.005	−0.077
	(-3.160)	(0.237)	(-0.592)	(-0.185)	(-1.161)
Impatient (1 = yes)	0.018	−0.221**	−0.170*	−0.038*	−0.052
	(1.255)	(-2.287)	(-1.703)	(-1.717)	(-0.690)
Access to extension services (1 = yes)	0.001	0.354***	0.333***	0.058***	0.297***
	(0.116)	(4.459)	(4.186)	(3.244)	(5.808)
Age of household head	0.008	0.474	0.481	0.138*	0.411*
	(0.263)	(1.314)	(1.366)	(1.860)	(1.807)
Education of household head	0.019	0.547***	0.498***	0.085***	0.113
	(1.483)	(3.637)	(3.364)	(2.609)	(1.189)
Female household head (1 = yes)	0.002	−0.117	−0.134	−0.020	−0.029
	(0.232)	(-0.996)	(-1.169)	(-0.857)	(-0.380)
Household size	0.011	0.549***	0.584***	0.030	0.389***
	(0.886)	(3.917)	(4.110)	(0.964)	(4.239)
Farm size	−0.051	1.062***	1.177***	0.041	0.544**
	(-0.568)	(2.876)	(3.087)	(0.504)	(2.283)
Used weather information (1 = yes)	0.001	0.029	−0.007	0.058***	0.079
	(0.106)	(0.328)	(-0.082)	(3.246)	(1.277)
Member of cooperative (1 = yes)	−0.002	0.143	0.141	0.036*	−0.019
	(-0.162)	(1.468)	(1.427)	(1.666)	(-0.246)
Observations	1324	1324	1324	1324	1324

Note: z-statistics in parentheses ***p < 0.01, **p < 0.05, *p < 0.1. Standard errors clustered at camp/ward level.

4. Farmer risk perceptions of CA

- Mapemba et al (2019): Malawi
- Ramsey et al (2019): USA
- Adhikari et al (2023):

Malawi

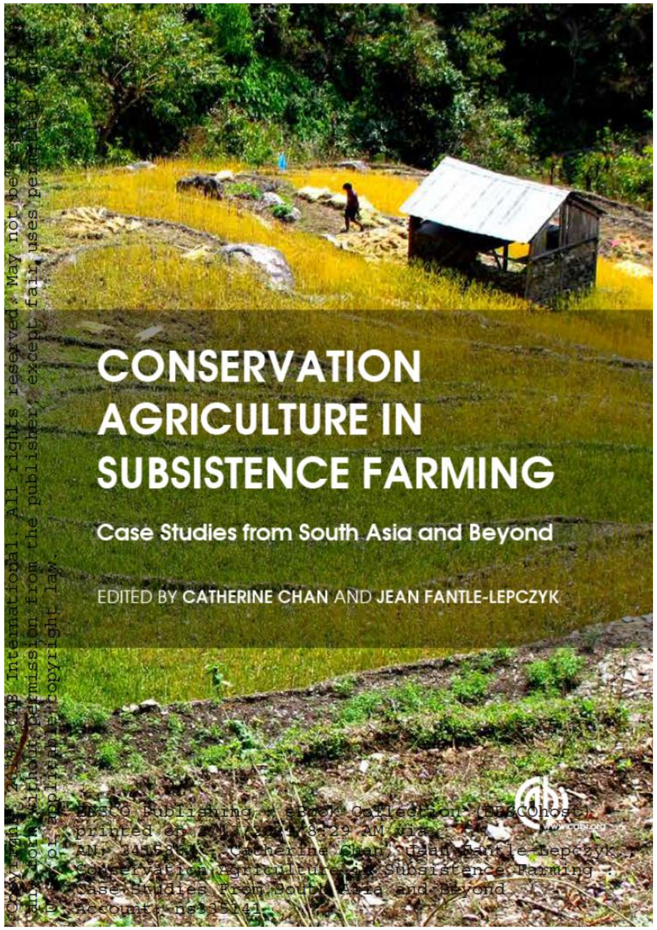


Table 6.2. Perceived riskiness of conventional agriculture versus conservation agriculture. (From author's own research, 2012.)

	Non-adopter (12 respondents)	Adopter (12 respondents)	All (24 respondents)	*P* value
Conventional is more risky than CA	75%	92%	83%	0.3^{NS}
CA is more risky than conventional	25%	8%	17%	0.3^{NS}
Total	100%	100%	100%	

NS, not significant.

6 Risk as a Determinant of Adoption of Conservation Agriculture by Smallholder Farmers in Malawi

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6. Conclusion

(a) Key messages on what works and where for risk-return outcomes

- Across all parts of the world, CA practices seem to offer economic returns
  - Some mixed effects for cover crops literature: USA (Lobell)
  - Zero or minimal tillage is found to maximize returns at minimal risk in most studies.

- In the case of CA, the overwhelming global evidence from long term experiments is that both risk-neutral and risk averse farmers will select CA.
- **But complex context matters.** For example: In Malawi, Ngwira et al (2013) found that in high elevations in Malawi the risk-return results of CA were unambiguous yet Kidane et al (2019) found them to be ambiguous in Mozambique.

- Most risk averse farmers may in some instances find conventional tillage more beneficial. This was the case for low elevation areas in Malawi **(Ngwira et al 2013)** and high elevation areas in Mozambique **(Kidane et al 2019)** and.

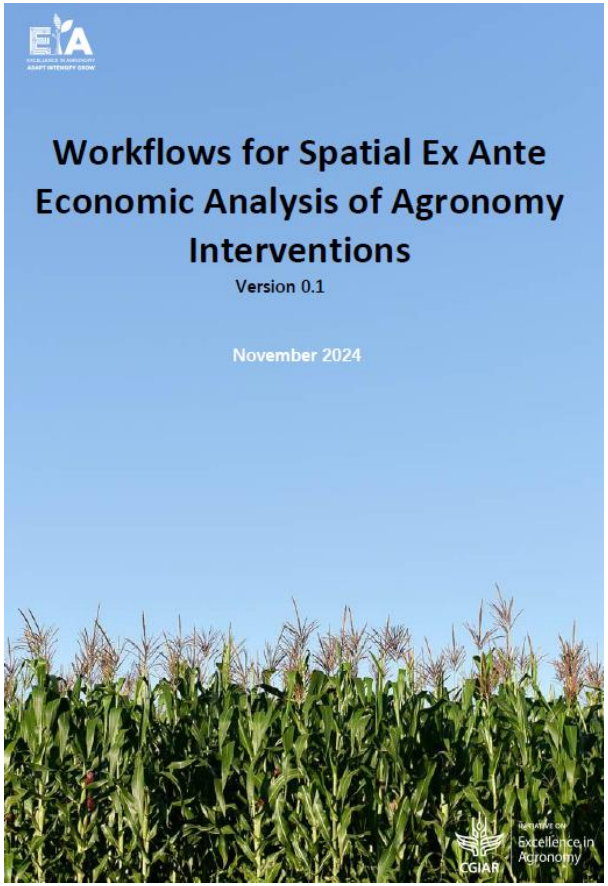
(b) Key messages on policies for encouraging adoption of CA that take into account risk aversion of the farmers

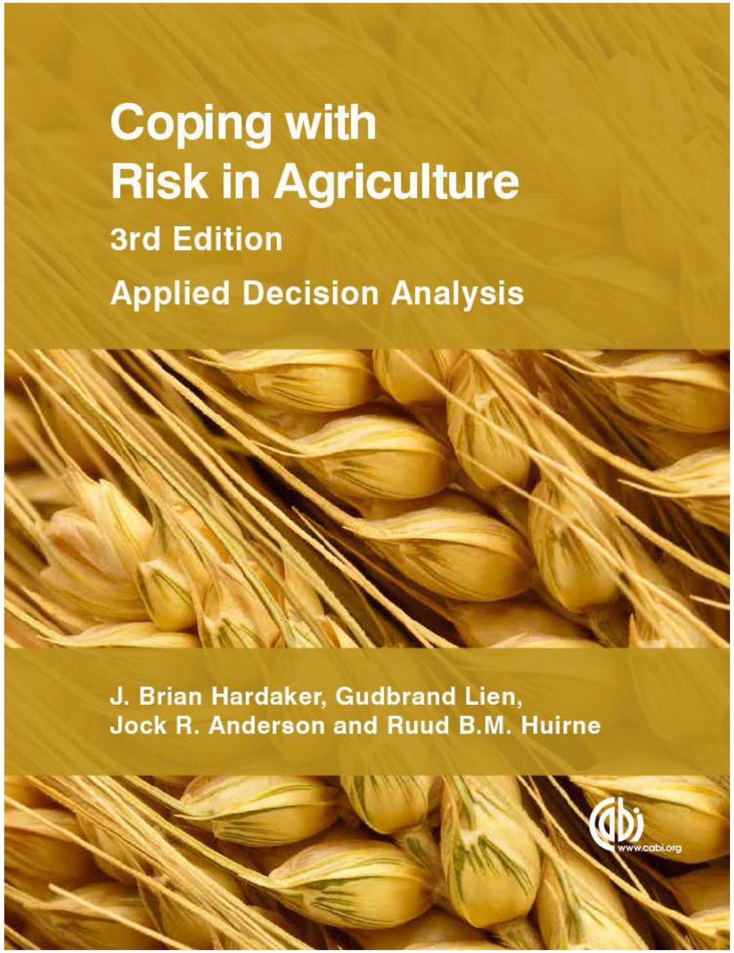
- Risk aversion matters for adoption.
- Beyond the actual influence on yield risk, farmer perception of technology matters.

(c) Key messages on risk perceptions and other behavioral biases

- Majority of farmers think CA is risk reducing (whether in USA or Malawi).
- Is it social desirability bias or their real perception?

For basics and more





Mkondiwa et al (2024) forthcoming. Url: https://maxwellmkondiwa.github.io/spatial_exante_sop_book/

Thank you for your interest!

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