Supplementary Material for Modeling Land Use and Land Cover Change: Using a Hindcast to Estimate Economic Parameters in gcamland v2.0

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1 Historical Context

1.1 Price, yield, and profit

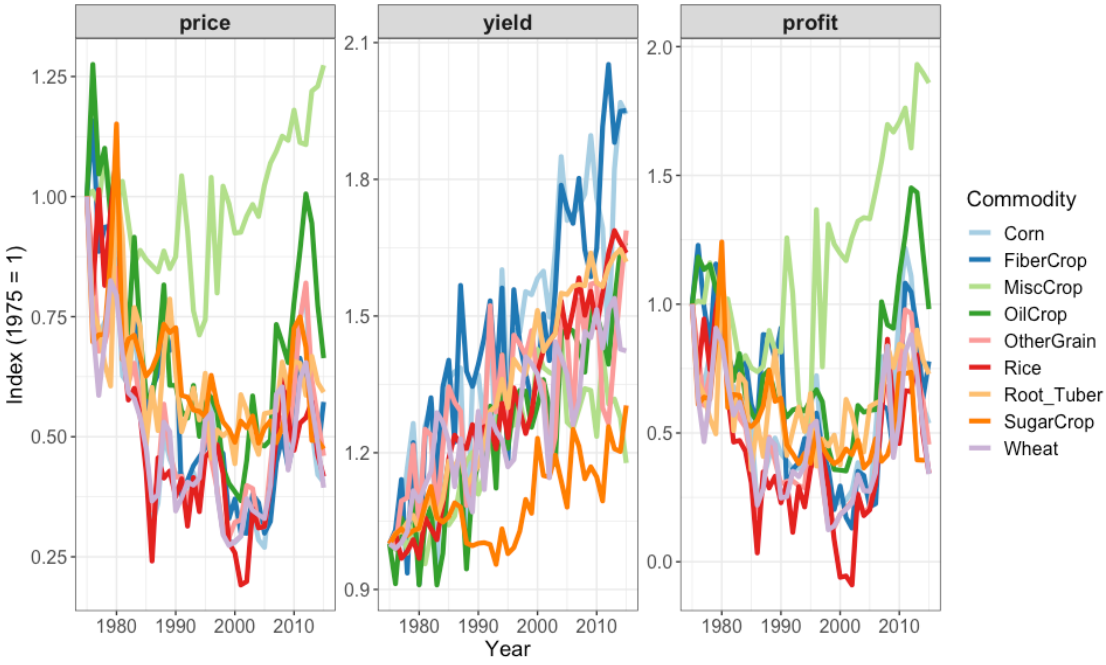


Figure S1: Price, Yield, and Profit by commodity from 1975 to 2015. Note that we use information from gcamland inputs to ensure consistent time series and units. The original inputs to gcamland are from FAO (for prices and yields) and USDA (for costs). Using only USDA information would not qualitatively change this figure.

1.2 Correlations between profit and yield

Figure S2 shows the change in area by crop as a function of the change in observed profit (i.e., perfect expectations). The correlation between expected profit and cropland area varies by crop, expectation scheme, and the time horizon (Figure S3). All crops have strong correlation between profit and area prior to 1990. However, in recent years, the correlation between profit and land area has changed. For crops where the market has changed dramatically (e.g., corn and soybeans), relying more heavily on recent information provides a better predictor of land area. This suggests that farmers growing these crops are weighting recent information about price and yield more heavily.

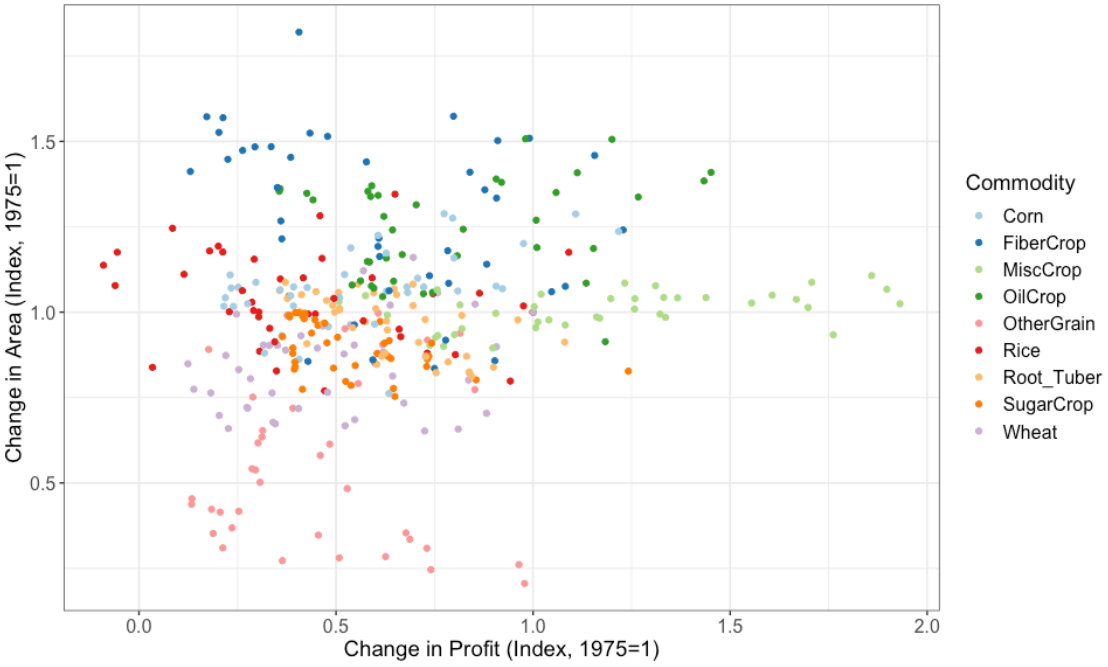
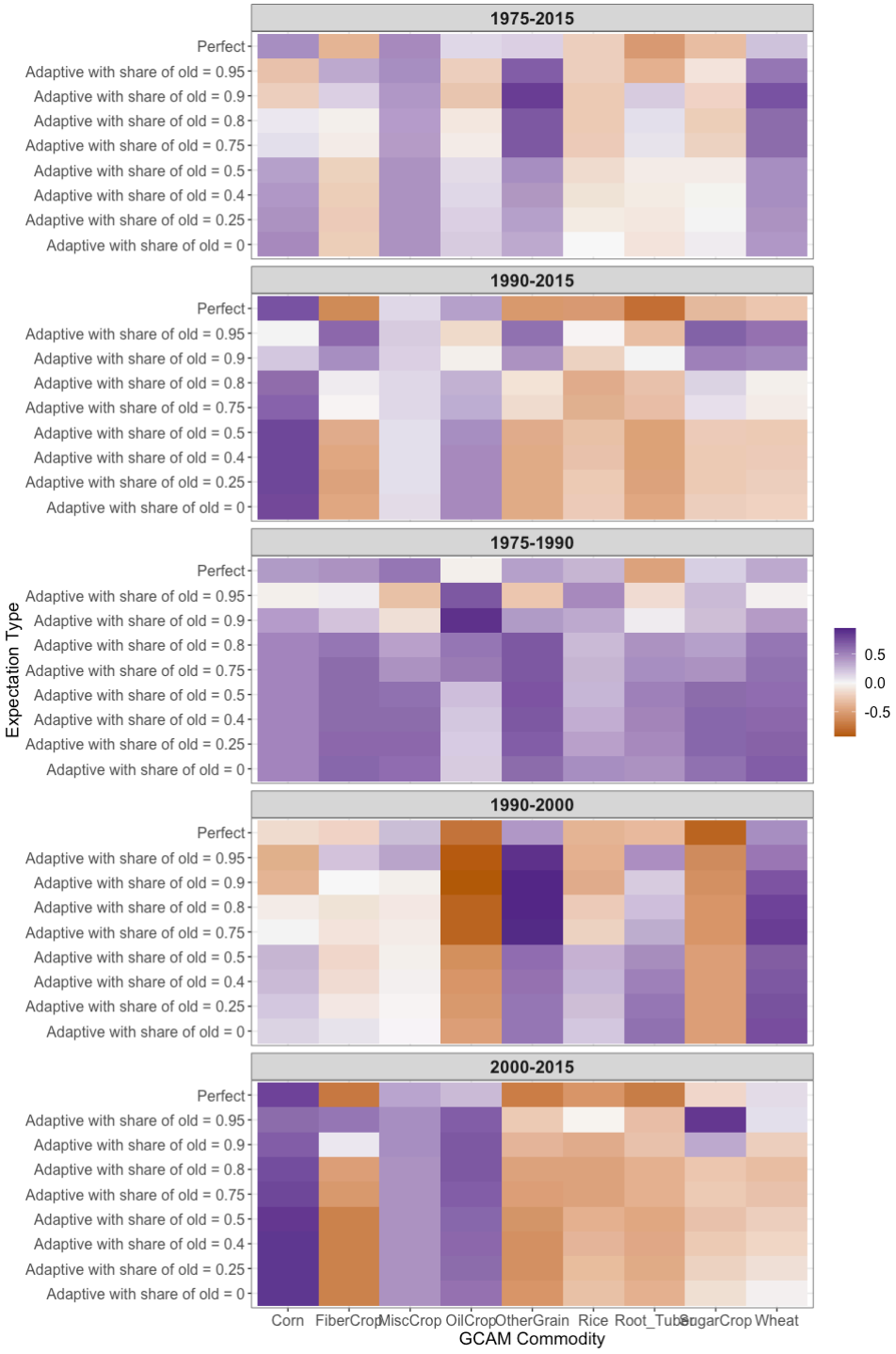


Figure S2: Correlation between change in observed profit (i.e., perfect expectations) as calculated in gcamland and change in cropland area from FAO (1975-2015). Each point is a crop-year combination.



25 **Figure S3: Pearson correlation coefficient between cropland area and expected profit, using FAO land and GCAM profits. Purple indicates correlation; Orange indicates anti-correlation.**

2 Additional Results

2.1 Parameter sets that minimize NRMSE

Table S1: Parameter Sets that Minimize NRMSE in the Default model

	Adaptive	Linear	Hybrid Linear Adaptive	Perfect
NRMSE	1.40	1.87	1.58	1.67
Logit (AgForest)	0.41	0.46	0.41	0.25
Logit (AgForest_NonPasture)	0.42	0.23	0.54	0.01
Logit (Cropland)	0.58	0.03	0.07	0.05
Share (Corn, OilCrop)	0.36	NA	0.71	NA
Share (Wheat, OtherGrain)	0.93	NA	0.86	NA
Share (All Other Crops)	0.99	NA	0.94	NA
Number of Years (Corn, OilCrop)	NA	16.00	21.00	NA
Number of Years (Wheat, OtherGrain)	NA	18.00	13.00	NA
Number of Years (All Other Crops)	NA	7.00	10.00	NA

2.2 Expected price, yield, and profit

Figure S4 shows the expected price, yield, and profit for the different expectation types, using the parameters that minimize NRMSE for those expectation types.

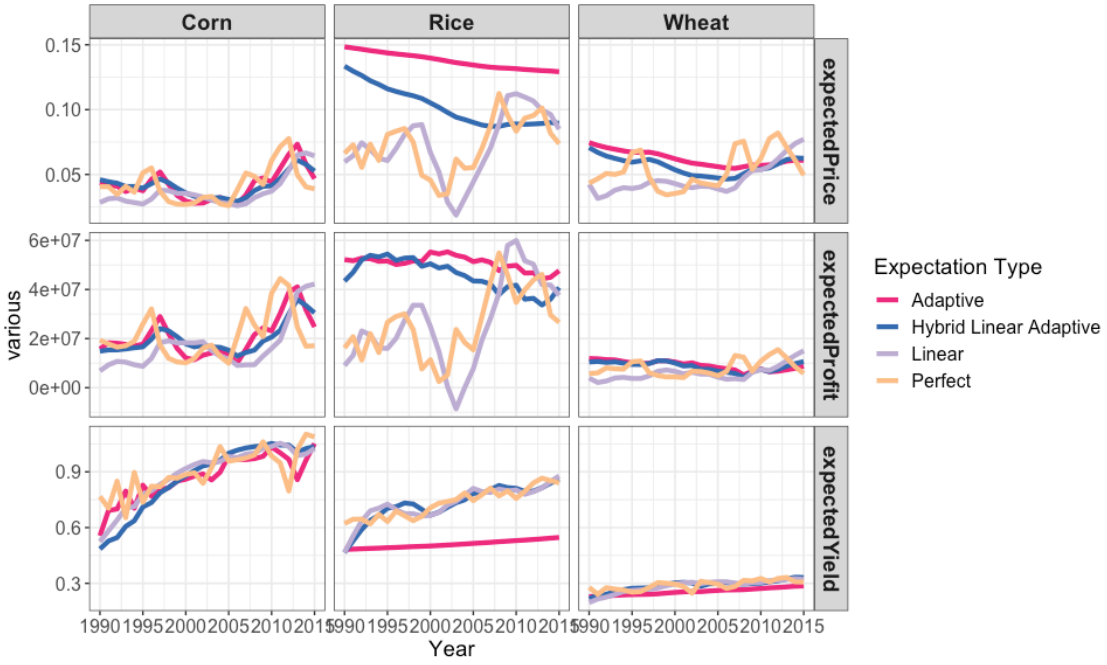


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Figure S4: Expected price, profit, and yield over time by expectation type and crop for the Default model.

2.3 Comparing modelled land to observations in the Default model

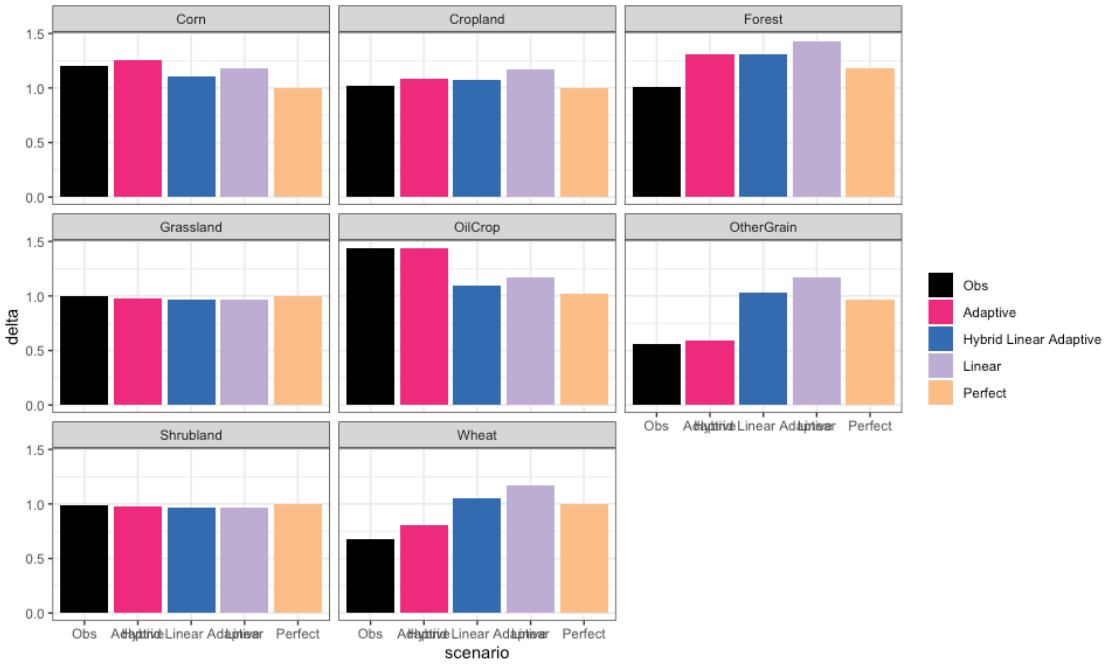

Figure S5: Net change in land cover and harvested cropland area (total and by crop) between 1990 and 2015. Black bar is observations (FAO or CCI). Colored bars are gcamland results for the models that minimize NRMSE. Note that fodder crops are excluded total cropland area in this figure due to data limitations. For forest, grassland, and shrubland, the observation data is net change between 1992 and 2015 due to data limitations.

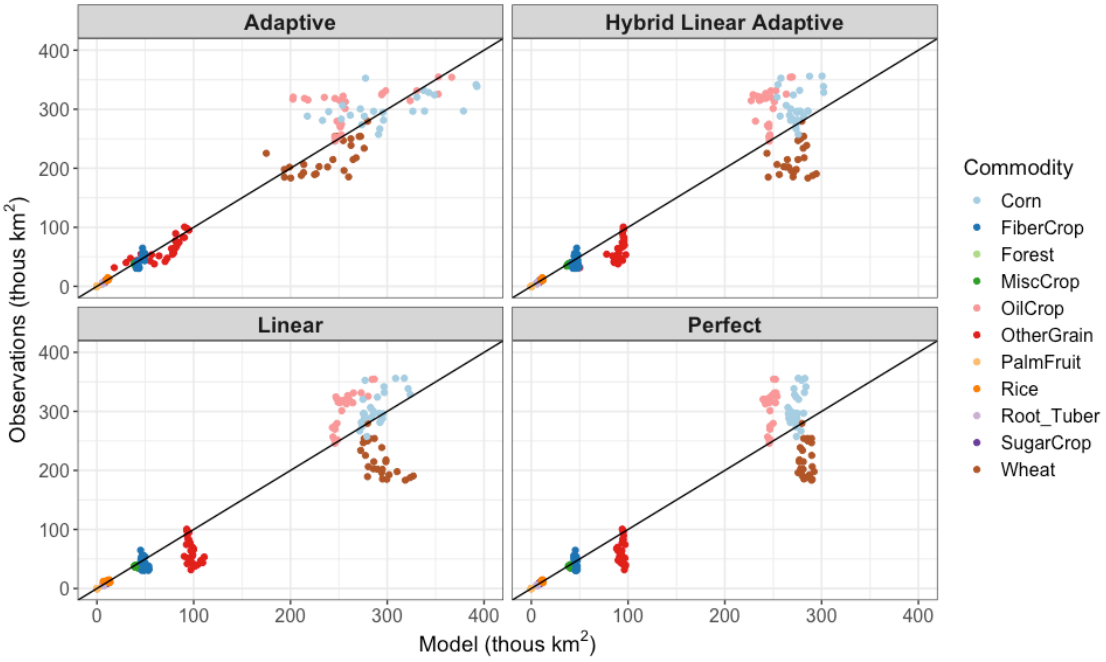

Figure S6: Model vs. Observations by Crop and Expectation Type (Harvested Area). Each point is a crop-year combination; each panel shows a different expectation type.

Due to differences in definitions of land cover between gcamland and the CCI land cover product, Grassland and Shrubland do not match in absolute value between gcamland and the observation data; however, the trends are reasonably similar. Forest is much more consistent, both in terms of magnitude and trends (Figure S7).

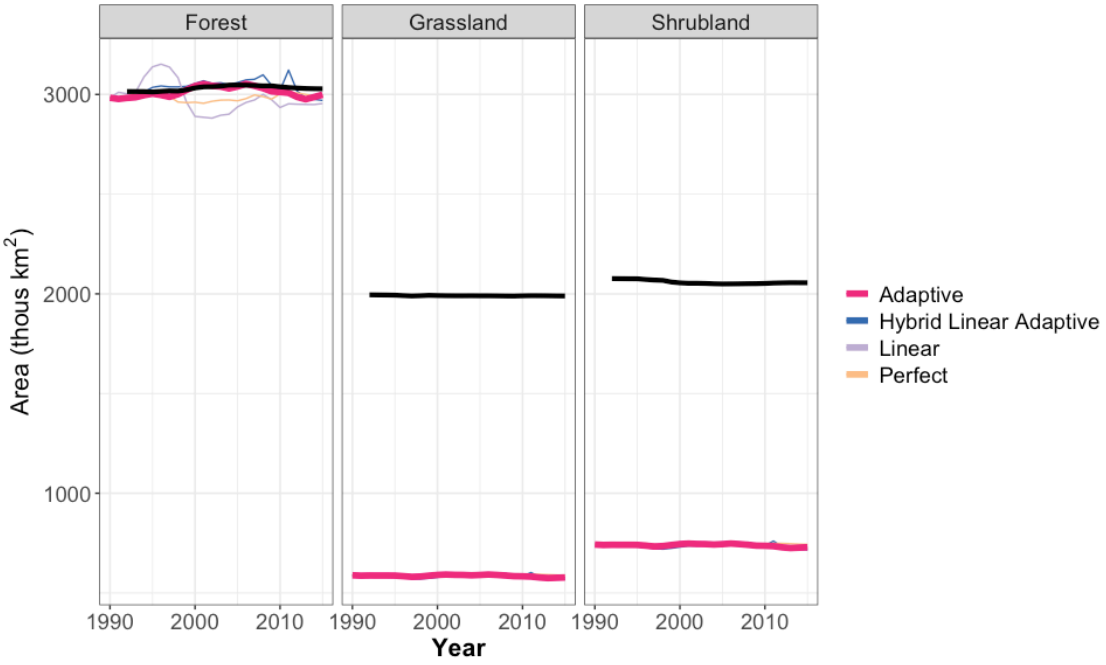

Figure S7: Land Cover over Time by Expectation Type. Black lines are data from the CCI satellite (downloaded from FAOSTAT).

We see similar results when comparing shares of harvested area by crop to observations (Figure S8) as shown when comparing absolute land area.

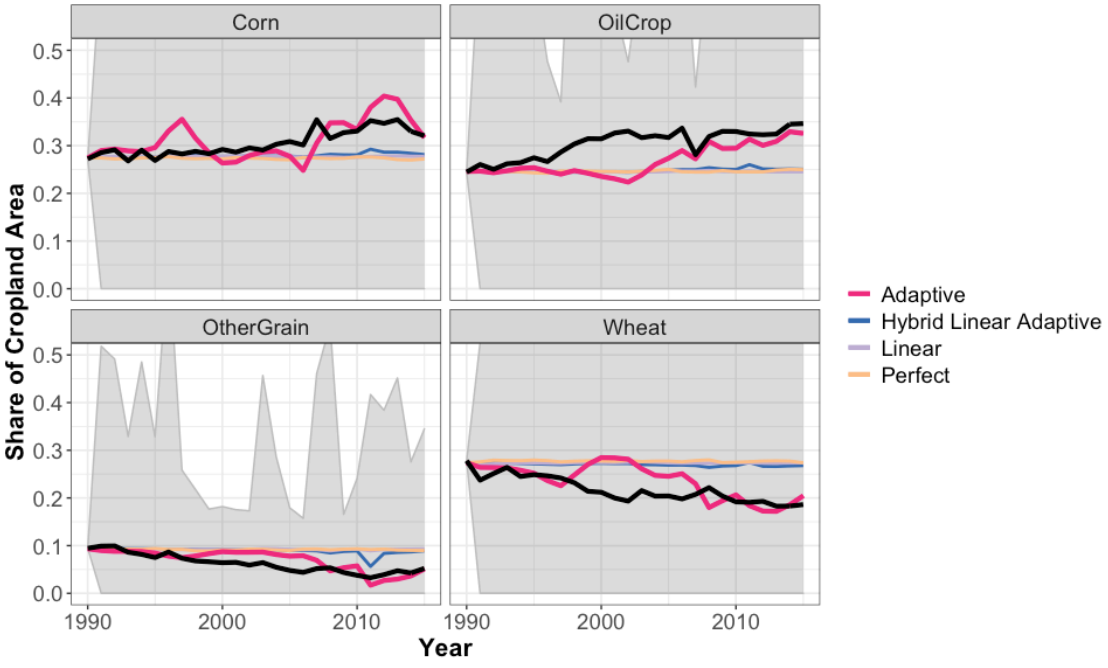

Figure S8: Cropland Share over Time by Crop and Expectation Type in the Default Model. Black lines are observations (FAO). Gray shading is the range across all gcamland simulations.

Figure S9 shows the NRMSE from the numerically optimal model in this paper to the NRMSE from the previous GCAM hindcast efforts (Snyder et al., 2017). We see improvements in all crops compared to the GCAM default in that paper ("Snyder2017_AY"). However, the variants from Snyder et al. (2017) that forecast yields and explicitly include biofuels policies ("Snyder2017_FYB") outperform the default assumptions in this paper for Corn and OilCrop when NRMSE is minimized across all crops. The parameter sets that explicitly minimize NRMSE for Corn only or for OilCrop only (labeled "ThisPaper_SingleCrop") in this paper have lower NRMSE than all variants in the Snyder et al. (2017) paper.

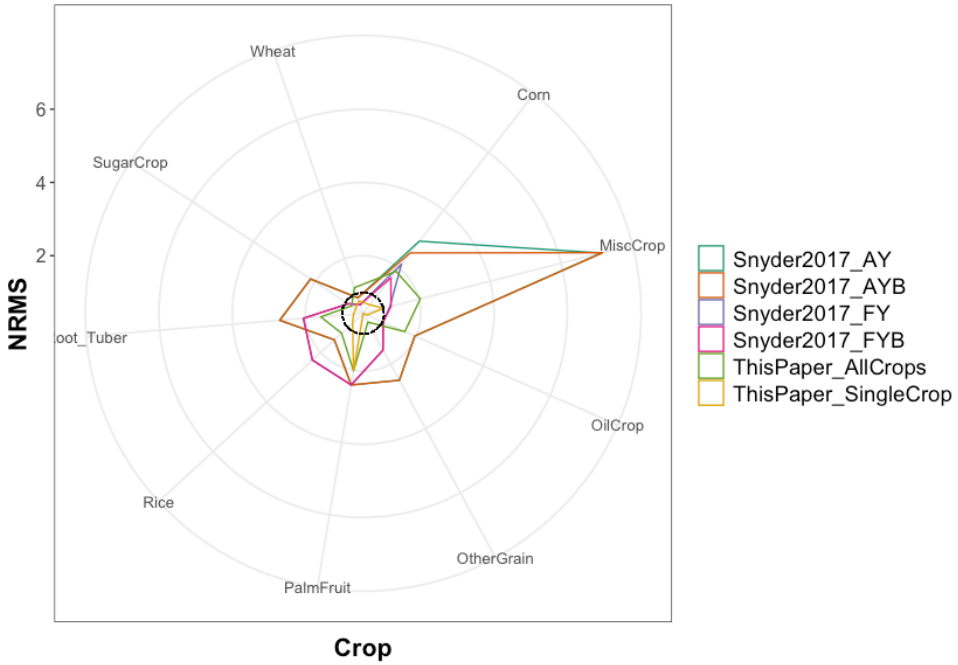

Figure S9: Comparing NRMSE from this paper to previous GCAM hindcast results from Snyder et al. (2017). Colored lines are different simulations from either the Snyder et al. (2017) paper or this paper.

3 Additional results from the sensitivity analyses

3.1 Sensitivity to model assumptions

Table S2: Parameter sets that minimize NRMSE for different modeling assumptions. Only the best model per assumption set is shown.

	Default	Same Parameters	With Subsidy
Expectation Type	Adaptive	Adaptive	Adaptive
NRMSE	1.399	1.531	1.4560
Logit (AgForest)	0.412	2.048	0.412

Logit (AgForest_NonPasture)	0.424	0.531	0.424
Logit (Cropland)	0.577	0.134	0.577
Share (Corn, OilCrop)	0.356	0.989	0.356
Share (Wheat, OtherGrain)	0.934	0.989	0.934
Share (All Other Crops)	0.988	0.989	0.988

3.2 Sensitivity to objective function

3.2.1 Optimizing for different objective functions

Table S3: Parameter sets that minimize different objective functions. Only the best model per assumption set is shown.

	NRMSE	RMSE	Bias	KGE
Expectation Type	Adaptive	Adaptive	Linear	Hybrid Linear Adaptive
Objective Value	1.399	16.14	5.51	0.761
Logit (AgForest)	0.412	0.412	2.175	0.527
Logit (AgForest_NonPasture)	0.424	0.424	1.38	0.051
Logit (Cropland)	0.577	0.577	0.278	0.365
Share (Corn, OilCrop)	0.356	0.356	NA	0.605
Share (Wheat, OtherGrain)	0.934	0.934	NA	0.951
Share (All Other Crops)	0.988	0.988	NA	0.925
Number of Years (Corn, OilCrop)	NA	NA	2	19
Number of Years (Wheat, OtherGrain)	NA	NA	25	15
Number of Years (All Other Crops)	NA	NA	5	12

3.2.2 Optimizing for different land types

Table S4: Parameter sets that minimize NRMSE over different land types. Only the best model per assumption set is shown.

	All Crops	Corn	OilCrop	Wheat	OtherGrain
Expectation Type	Adaptive	Hybrid Linear Adaptive	Linear	Adaptive	Adaptive
NRMSE	1.399	0.732	0.545	0.926	0.496
Logit (AgForest)	0.412	0.224	2.459	2.454	0.815
Logit (AgForest_NonPasture)	0.424	1.383	0.279	1.976	2.340
Logit (Cropland)	0.577	0.222	0.093	0.811	0.603
Share (Corn, OilCrop)	0.356	0.988	NA	0.294	0.789
Share (Wheat, OtherGrain)	0.934	0.497	NA	0.953	0.928
Share (All Other Crops)	0.988	0.876	NA	0.929	0.957
Number of Years (Corn, OilCrop)	NA	21	18	NA	NA
Number of Years (Wheat, OtherGrain)	NA	4	16	NA	NA
Number of Years (All Other Crops)	NA	20	18	NA	NA

3.3 Sensitivity to calibration year and/or time step

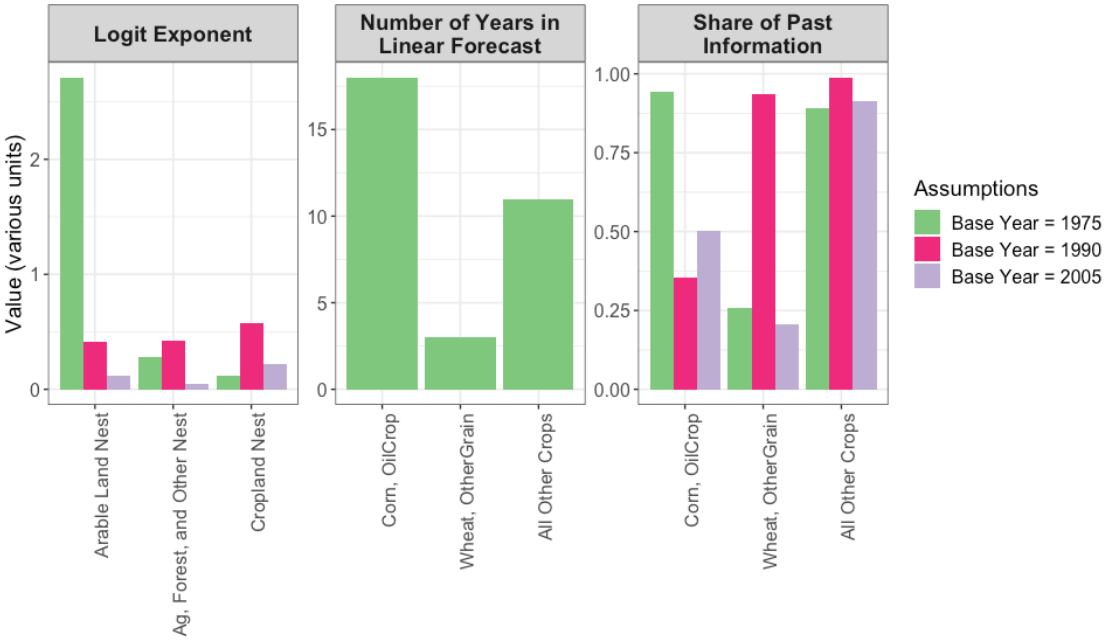

Figure S10: Parameter sets that minimize NRMSE for different calibration years.

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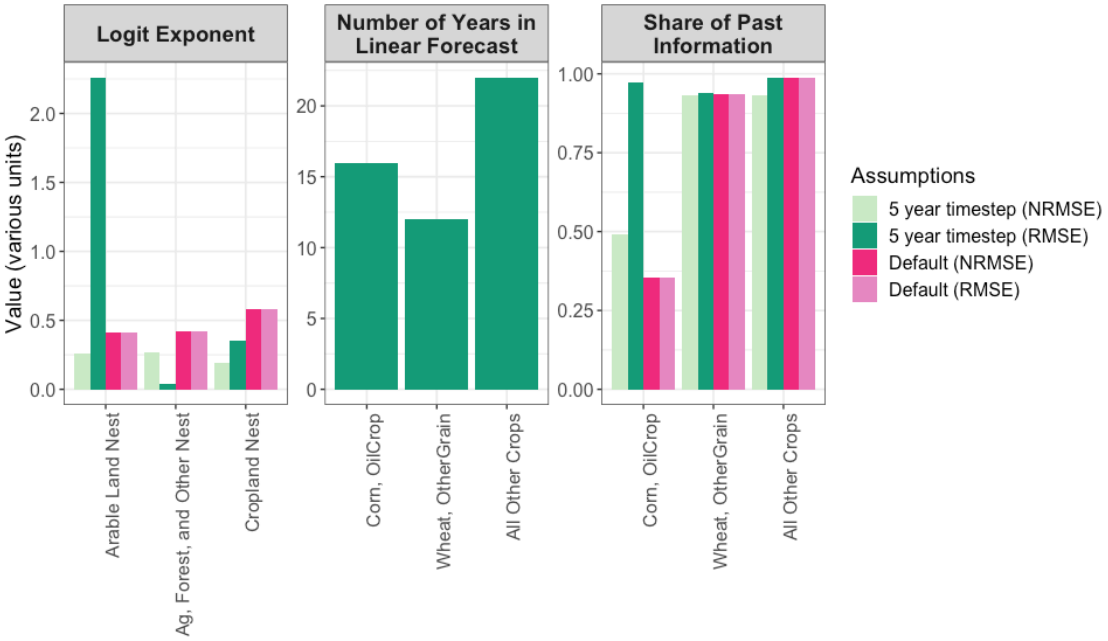

Figure S11: Parameter sets that minimize NRMSE or RMSE for different model time steps.

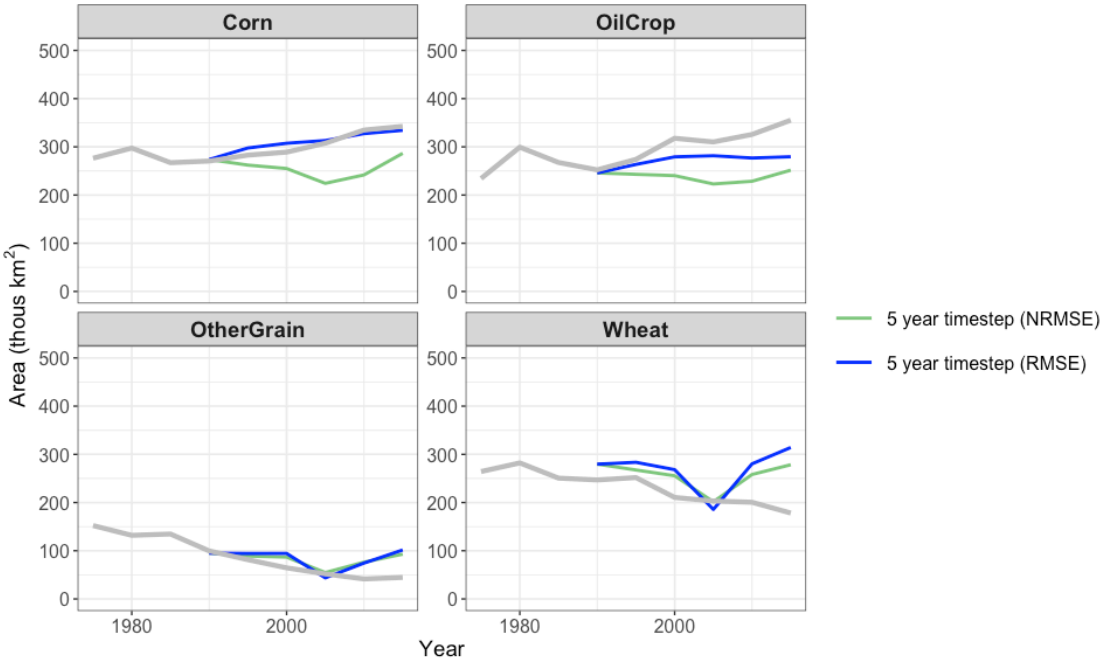

Figure S12: Harvested area by crop with five year time steps, including parameter sets that minimize RMSE and parameter sets that minimize NRMSE. Gray line is five year average of observations (FAO). Green line is NRMSE; blue line is RMSE.

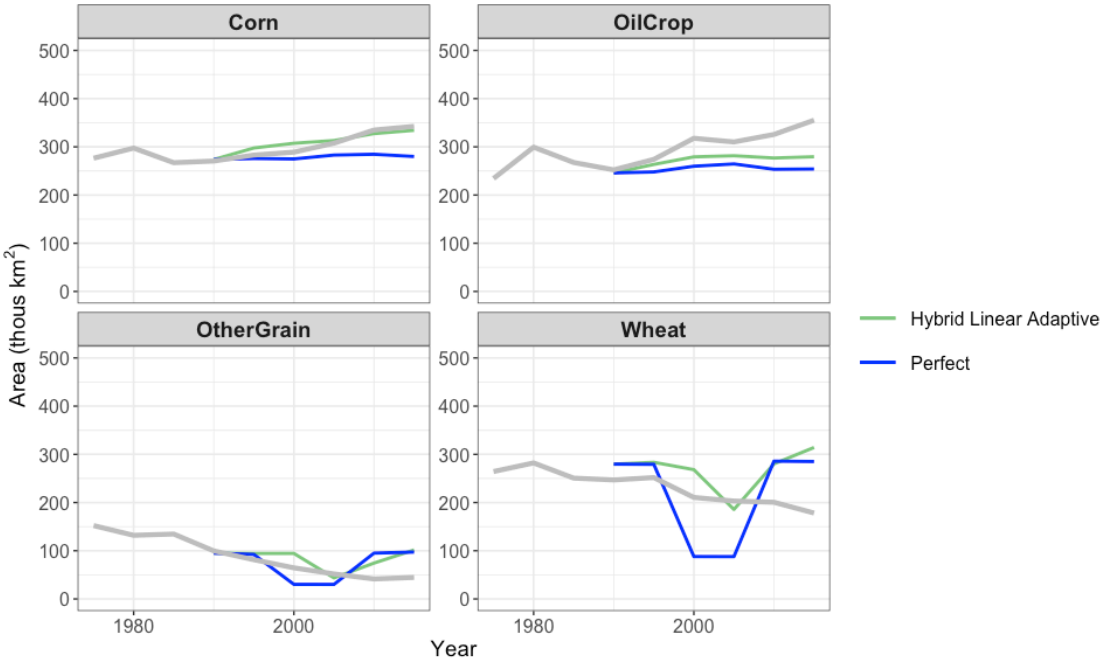

Figure S13: Harvested area by crop with five-year time steps, using parameter sets that minimize RMSE. Gray line is five-year average of observations (FAO). Green line is adaptive expectations; blue line is perfect expectations.

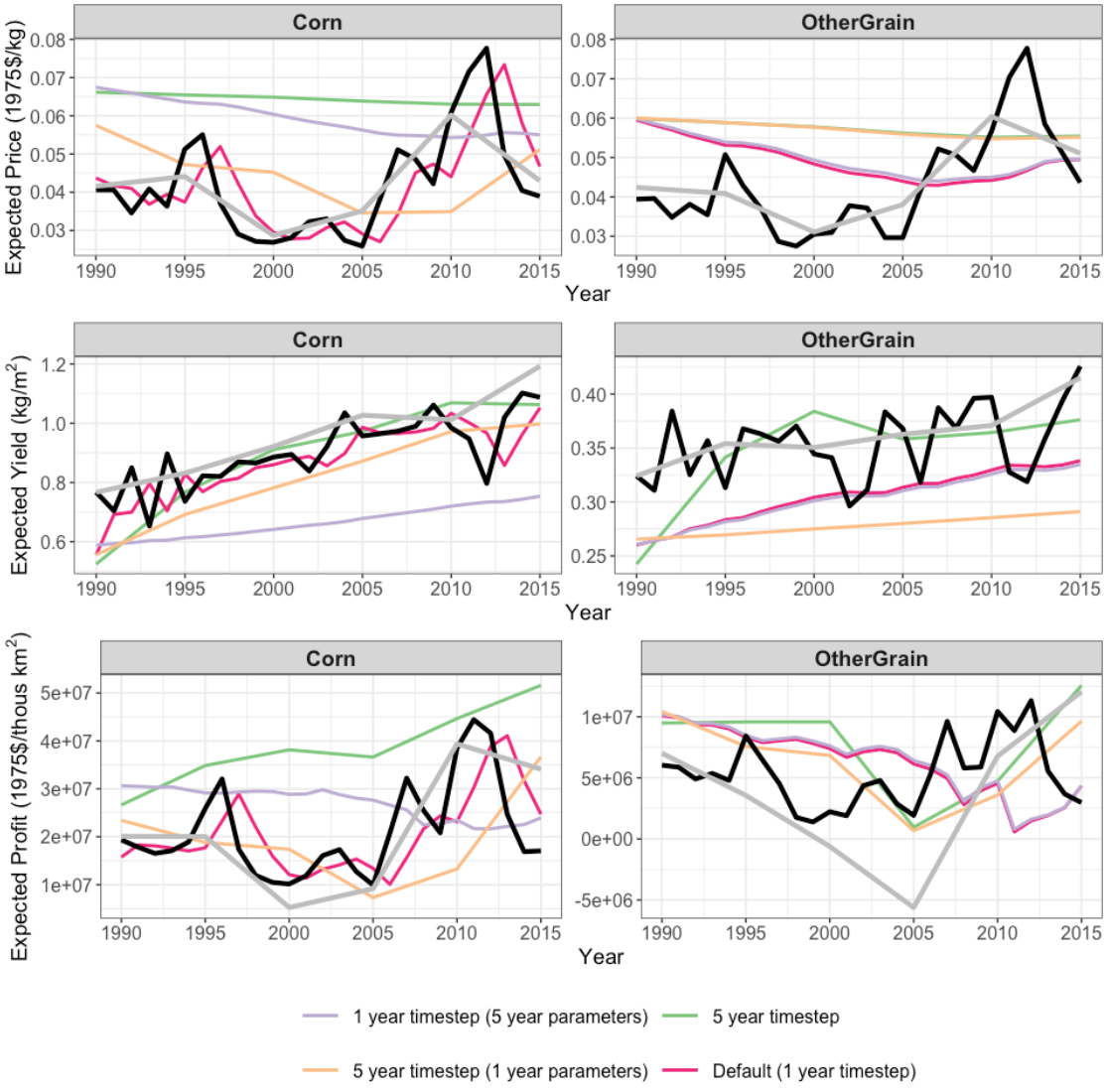

Figure S14: Expected price, yield, and profit by crop under different model time steps and parameter sets, using parameter sets that minimize RMSE. Black line is annual observations; gray line is five-year averages of observations (FAO). Colored lines are different combinations of time steps and parameter sets. Note that the parameter set that minimizes RMSE also minimizes NRMSE for the Default model.

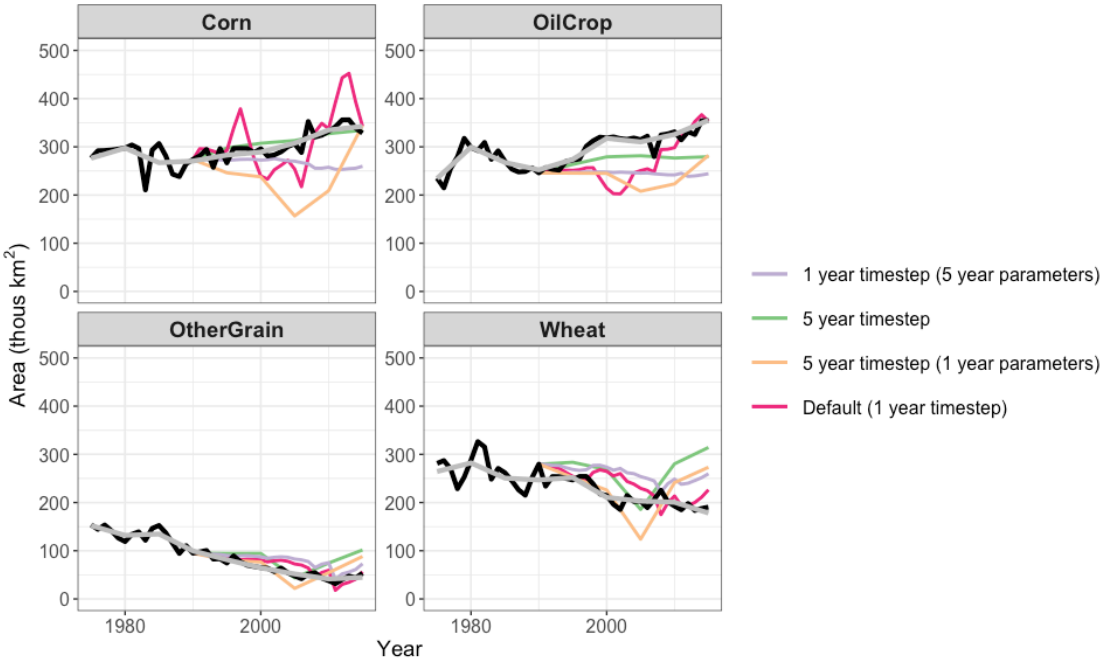

Figure S15: Harvested area by crop under different model time steps and parameter sets, using parameter sets that minimize RMSE. Black line is annual observations; gray line is five-year averages of observations (FAO). Colored lines are different combinations of time steps and parameter sets. Note that the parameter set that minimizes RMSE also minimizes NRMSE for the Default model.

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