# Econometric Estimation of Land-use Conversion under Climate Change in the Conterminous United States


Chris Mihiar

U.S. Forest Service

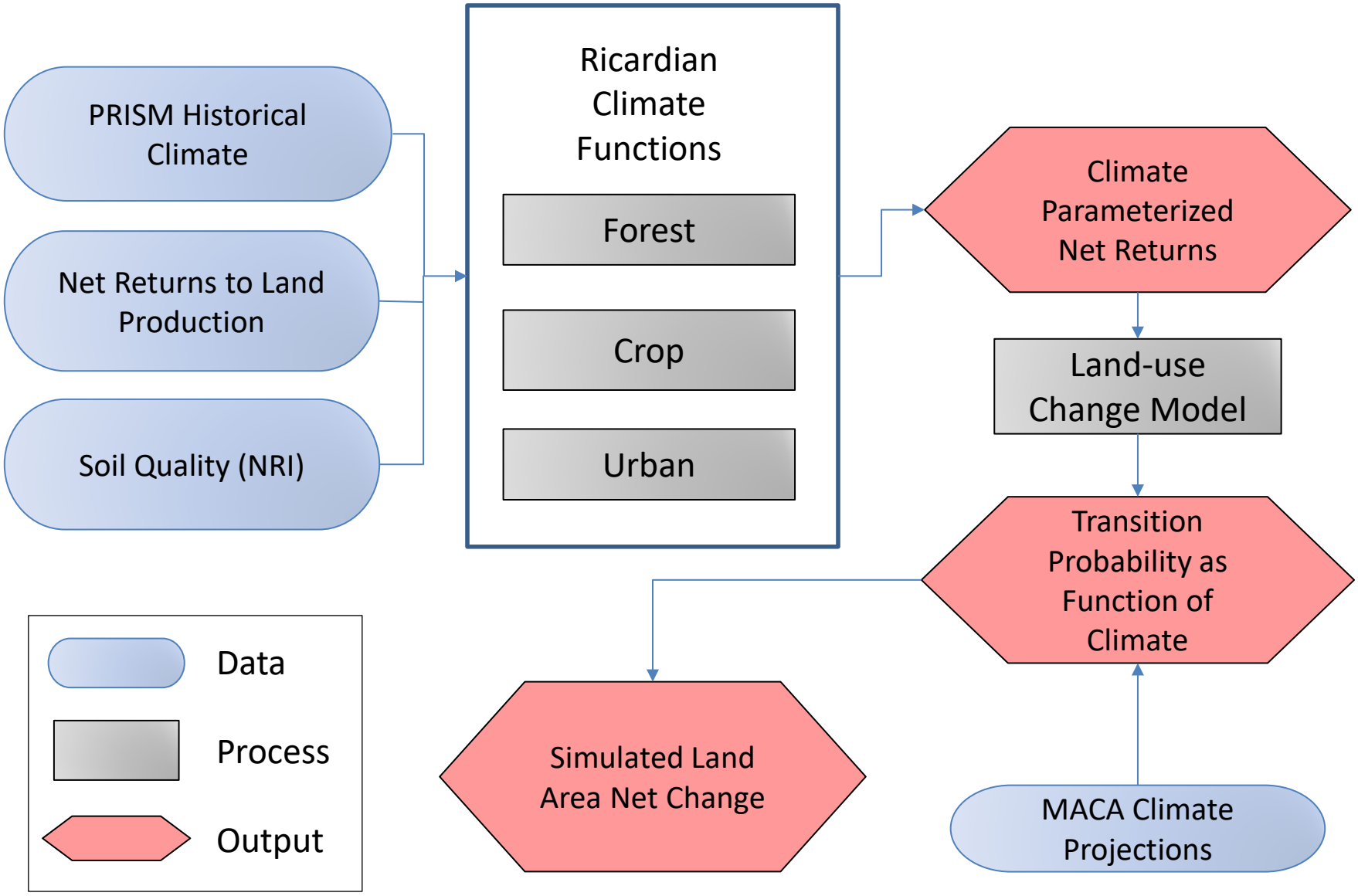
Dave Lewis

Oregon State University


SOFAC Annual Meeting
August 10, 2020

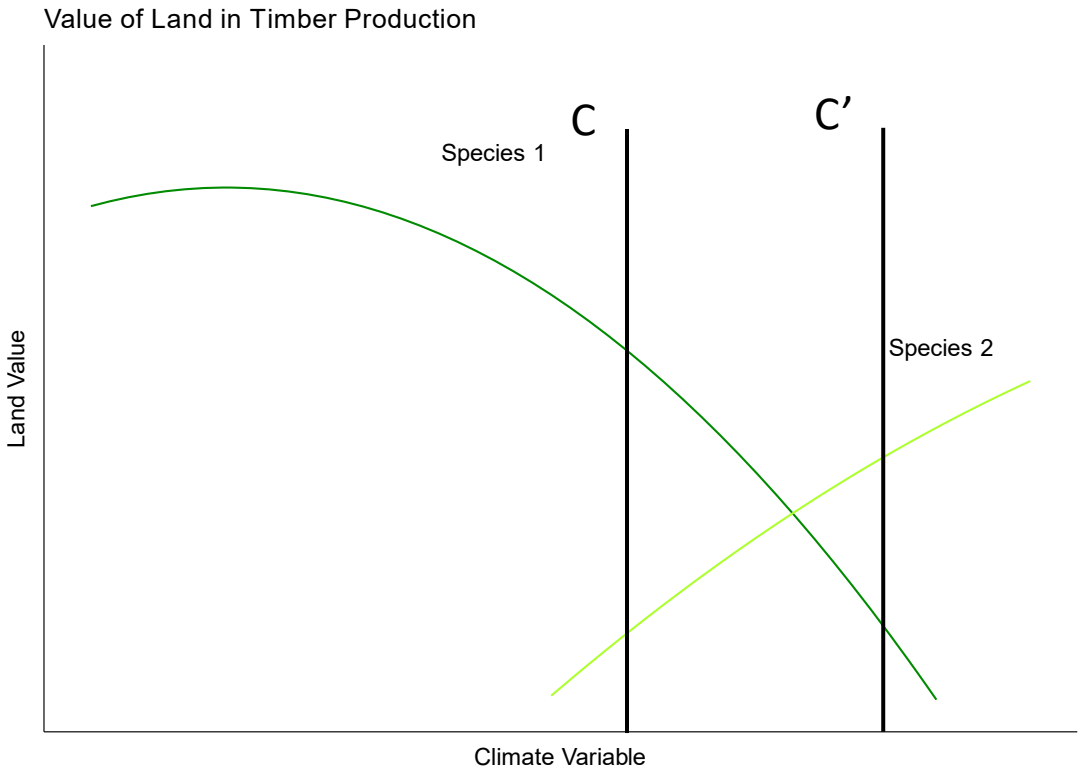
# Overview

- Integration of Ricardian climate impact models (with adaptation) and a discrete-choice land-use change model
- Analysis of 2 key forms of uncertainty
  - Climate model uncertainty
  - Estimated parameter uncertainty
- Using baselines that include climate change are necessary
- Takeaways
  - Drier and warmer climate scenarios favor forest land
  - Wetter and cooler climate scenarios favor urban land development
  - Wetter and warmer scenarios favor crop land


PRISM Historical Climate
Net Returns to Land Production
Soil Quality (NRI)
Ricardian Climate Functions
Forest
Crop
Urban
Climate Parameterized Net Returns
Land-use Change Model
Transition Probability as Function of Climate
Simulated Land Area Net Change
MACA Climate Projections
Data
Process
Output

# Ricardian value and climate adaptation

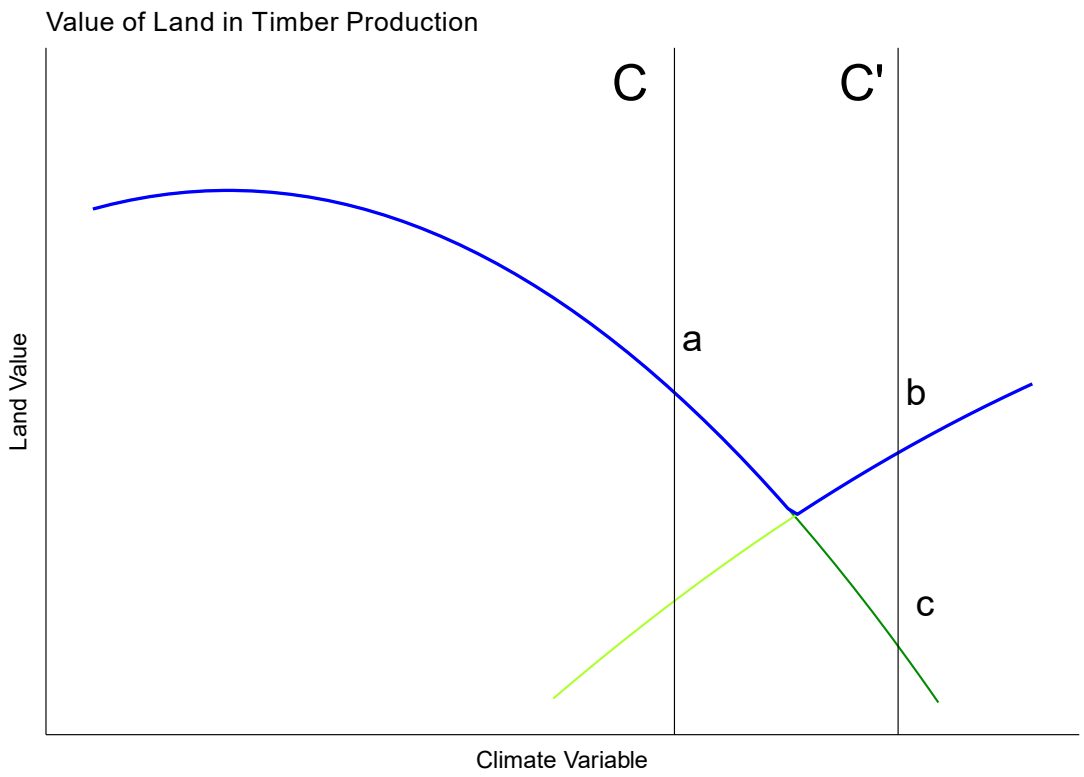
- Broad land-use adaptation must also account for intensive adaptation
- One example: changing planted species
- Land value varies across levels of climate, and across species.



# Ricardian value and climate adaptation

Consider a change in climate from C to C’

- From a to c represents adjustments on the intensive margin.
- From a to b represents adjustments on the intensive and extensive margins




Ex/ Mendelsohn, R., Nordhaus, W., & Shaw, D. (1994). The Impact of Global Warming on Agriculture: A Ricardian Analysis. American Economic Review.

# Forest Climate Model

$$NR^f = \alpha + \beta f(AnnualTemp, AnnualPrecip) + \gamma LCC + \epsilon$$

- $NR^f$ is the net economic return to an acre of forest land
- $AnnualTemp$ and $AnnualPrecip$ are weighted climate (30yr mean) measures weighted by current forest landscape
- Climate variables enter the specifications as 4$^{th}$ order polynomials with an interaction term between temp and precip
- $LCC$ is the Land Capability Class, a measure of soil quality from the NRI survey

| | TEMP | PRECIP |
|---|---|---|
| Average Marginal Effect | 2.49***<br>(0.142) | -0.005**<br>(-0.0026) |

Mihiar and Lewis. 2021. Land Economics

# Crop Climate Model

$$NR^c = \alpha + \beta f(SeasonalTemp, SeasonalPrecip) + \gamma LCC + \epsilon$$

- $NR^c$ is the net economic return to an acre of crop land; data from BEA surveys of farm revenues and costs
- Seasonal averages of temp and precip for each county enter the specification in quadratic form with an interaction term
- $LCC$ is the Land Capability Class, a measure of soil quality from the NRI survey

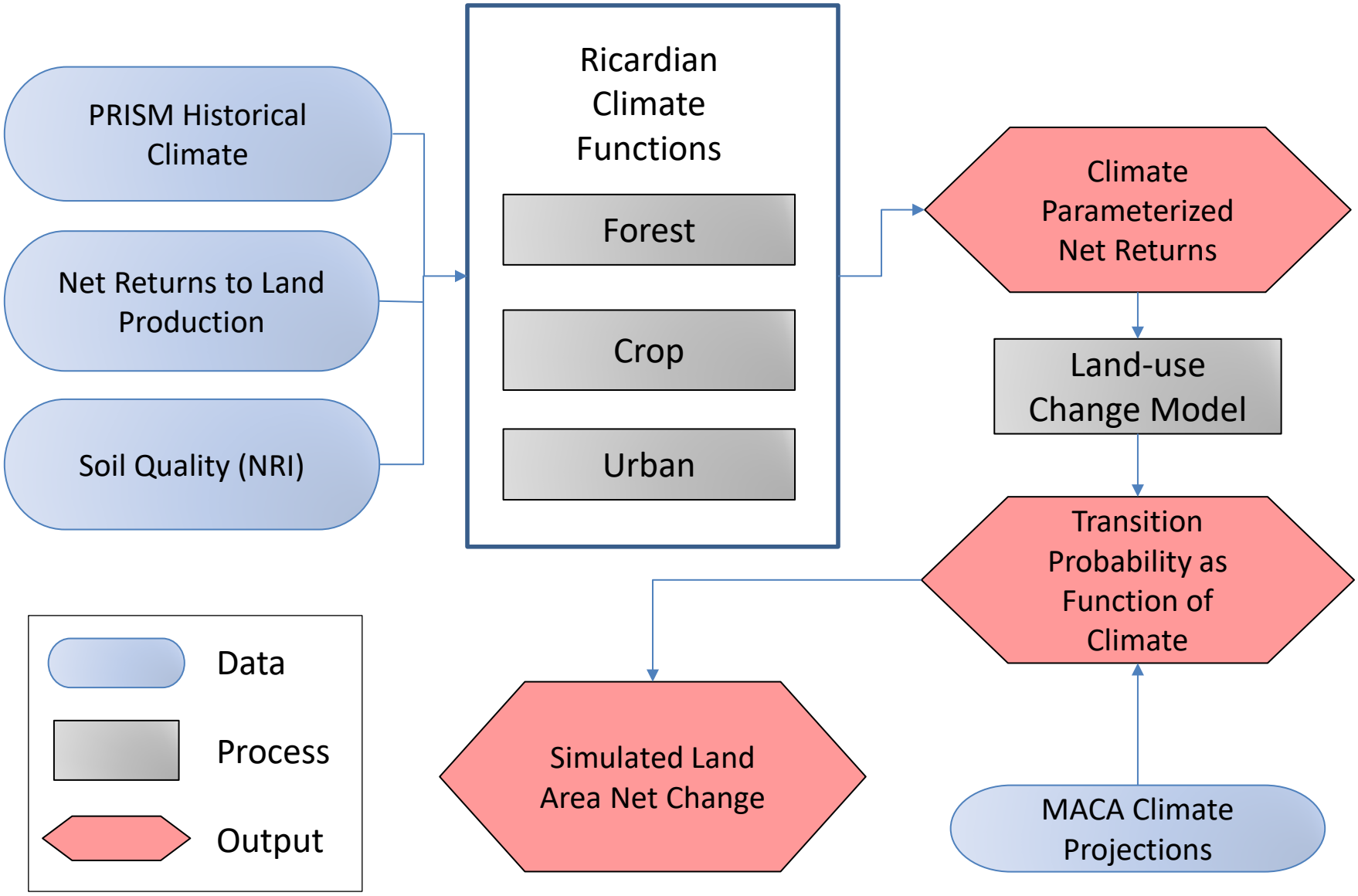
| | Spring | Summer | Fall | Winter |
|---|---|---|---|---|
| Temp AME | -21.29***<br>(3.37) | 0.11<br>(3.41) | 18.39***<br>(4.99) | 4.19<br>(2.85) |
| Precip AME | 0.006<br>(0.053) | -0.006<br>(0.025) | -0.202***<br>(0.050) | 0.190***<br>(0.038) |

# Urban Climate Model

$$NR^u = \alpha + \beta f(HDD, CDD) + \gamma g(pop, inc) + \phi X + \epsilon$$

- $NR^u$ is the net economic return to an acre of urban land
- $hdd$ and $cdd$ are heating and cooling degree days
- $inc$ and $pop$ are personal income ($2010) and population count per square mile
- $X$ includes control variables: education and race

| | HDD | CDD | PPT | Inc | Pop |
|---|---|---|---|---|---|
| Average Marginal Effect | -38.5*** (1.55) | -114.5*** (3.61) | -11.0*** (2.30) | 0.45*** (0.04) | 718.8* (382.06) |


PRISM Historical Climate
Net Returns to Land Production
Soil Quality (NRI)
Ricardian Climate Functions
Forest
Crop
Urban
Climate Parameterized Net Returns
Land-use Change Model
Transition Probability as Function of Climate
Simulated Land Area Net Change
MACA Climate Projections
Data
Process
Output

# Land-use change model

**Transition Probability Function**

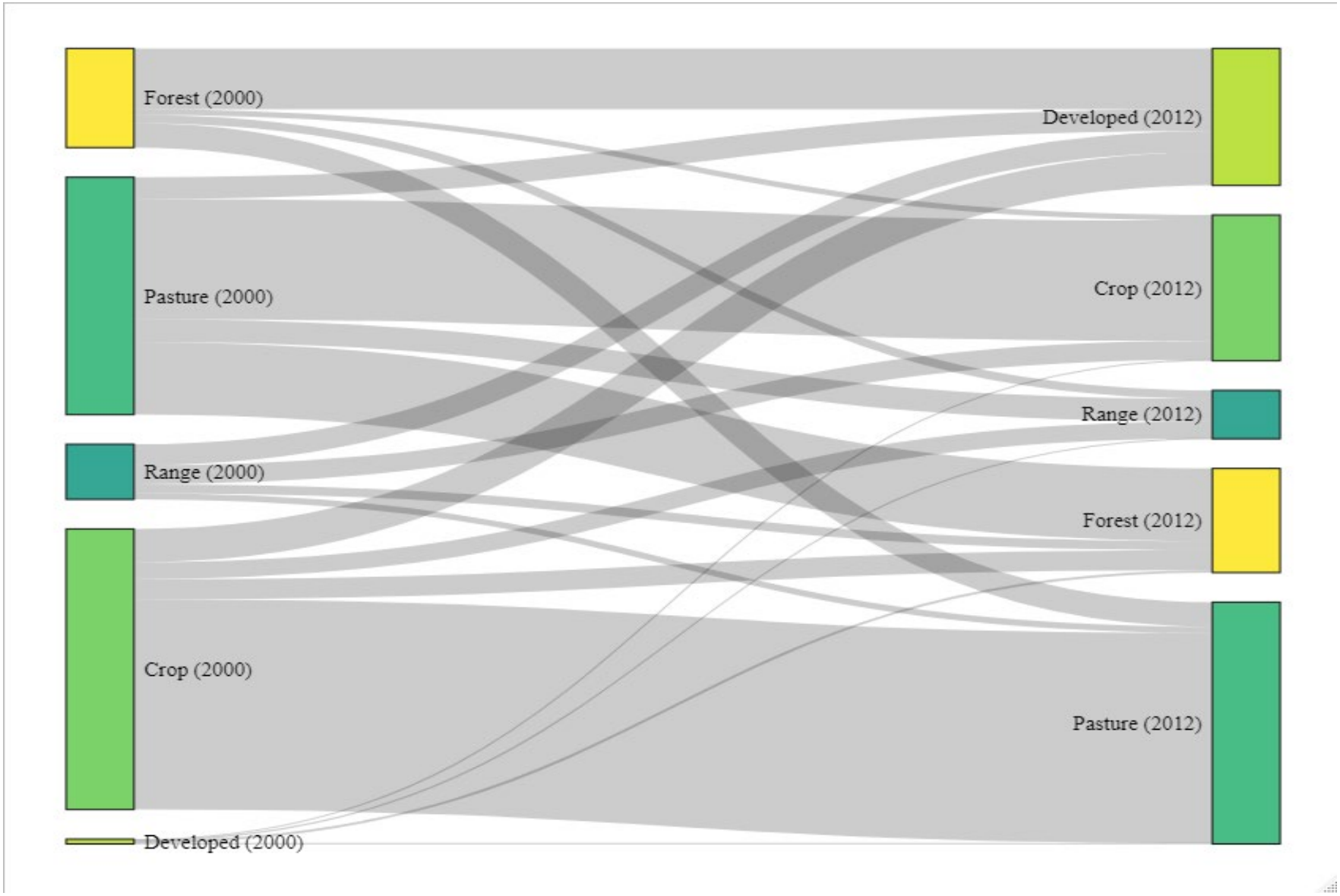
$$P_{ijk} = f(NR^c(C), NR^f(C), NR^u(C, Pop, Inc) | LCC_i)$$

- Probability of plot *i* converting from land-use *j* to *k* is a function of net returns, population, and income conditional on land quality

- Four functions are estimated for starting uses:
  - Forest, Crop, Pasture, and Range

- Estimated by multinomial logit
  - Choice set varies by county using currently observed landscape
  - Spatial unobservable factors modeled using BLP contraction mapping
  - Data from National Resource Inventory (NRI)
    - 2000-2012
    - Non-federal land

# Observing Land-use Change with NRI data



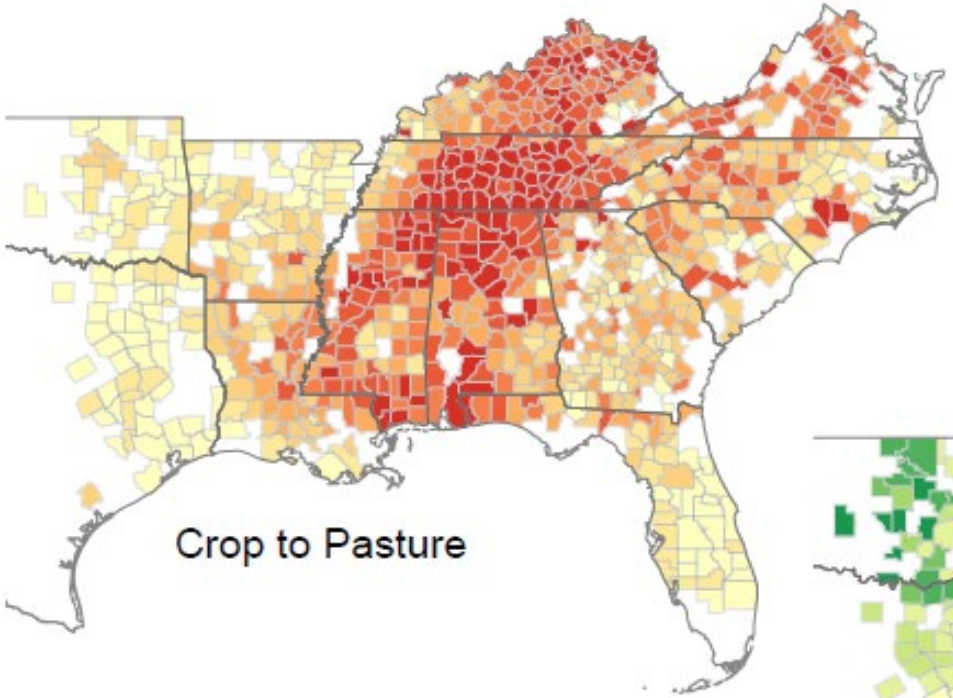
# Southeast U.S. example

Most active margins between 2000-2012

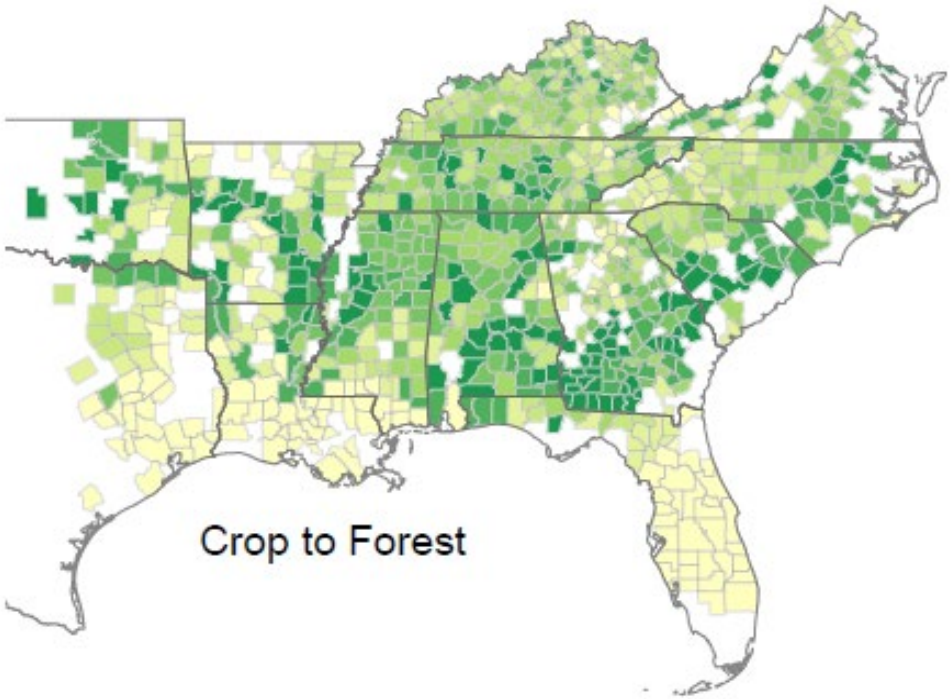
| Transition Type | Millions of acres |
|---|---|
| Crop to pasture | 7 |
| Pasture to crop | 3.5 |
| Pasture to forest | 3.3 |
| Forest to pasture | 1.3 |
| Forest to urban | 3 |

- Southeast defined to include parcels east of the 100$^{th}$ meridian and in the southern forest service region
- Observed behavior determines choice set; varies across regions

# Cropland that would have moved to pasture is more likely to move into forest




**Change in Transition Probability**

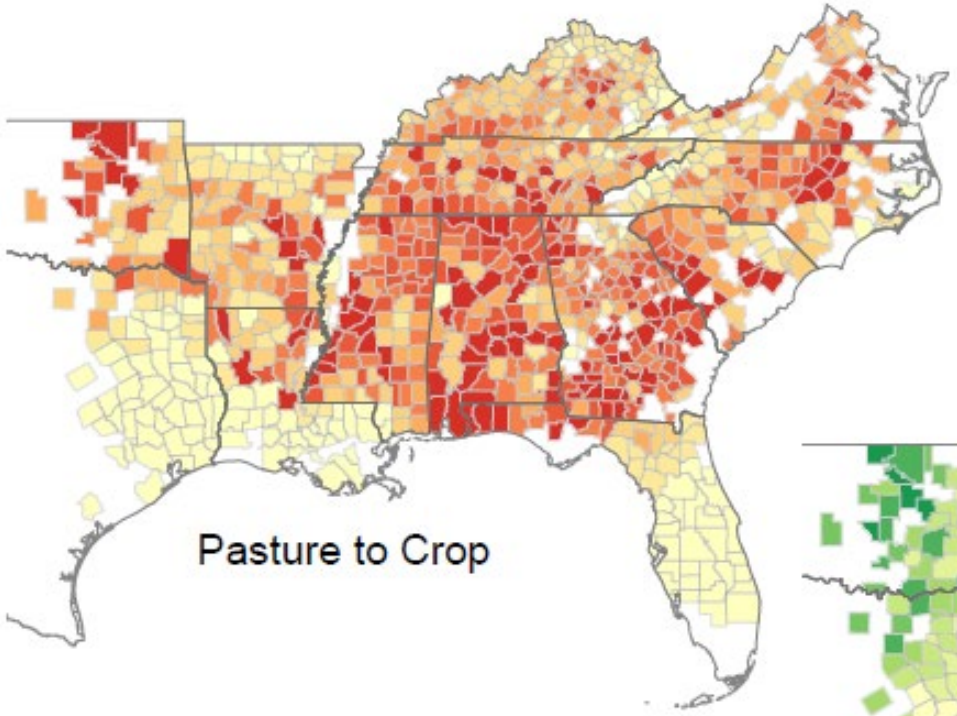



Yellow → No Impact

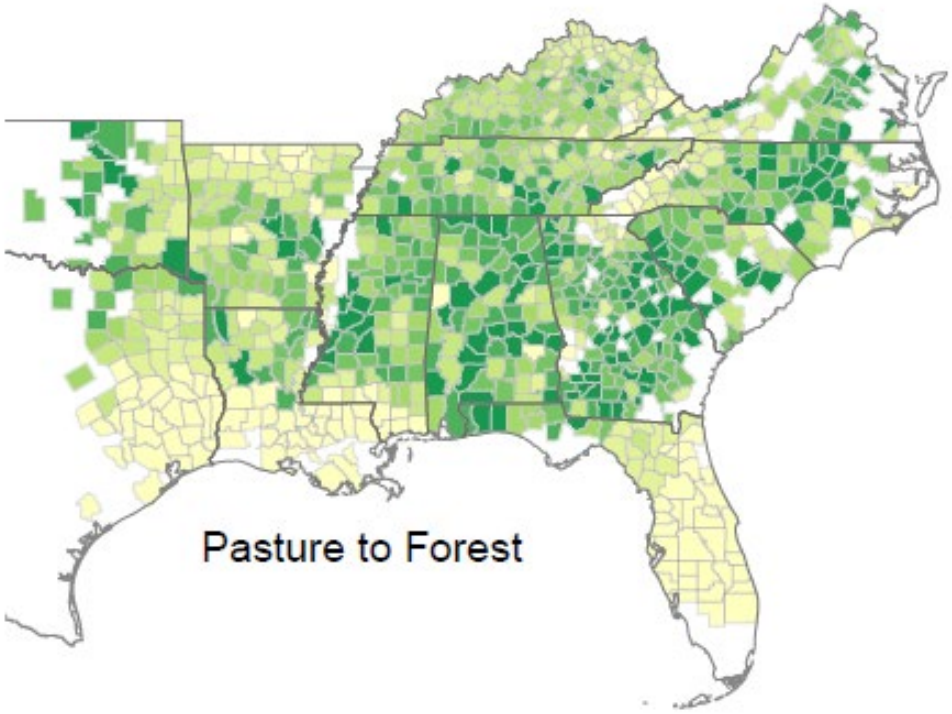
Red → Less Likely

Green → More Likely

# Pasture is more likely to move into forest at the expense of new cropland




**Change in Transition Probability**

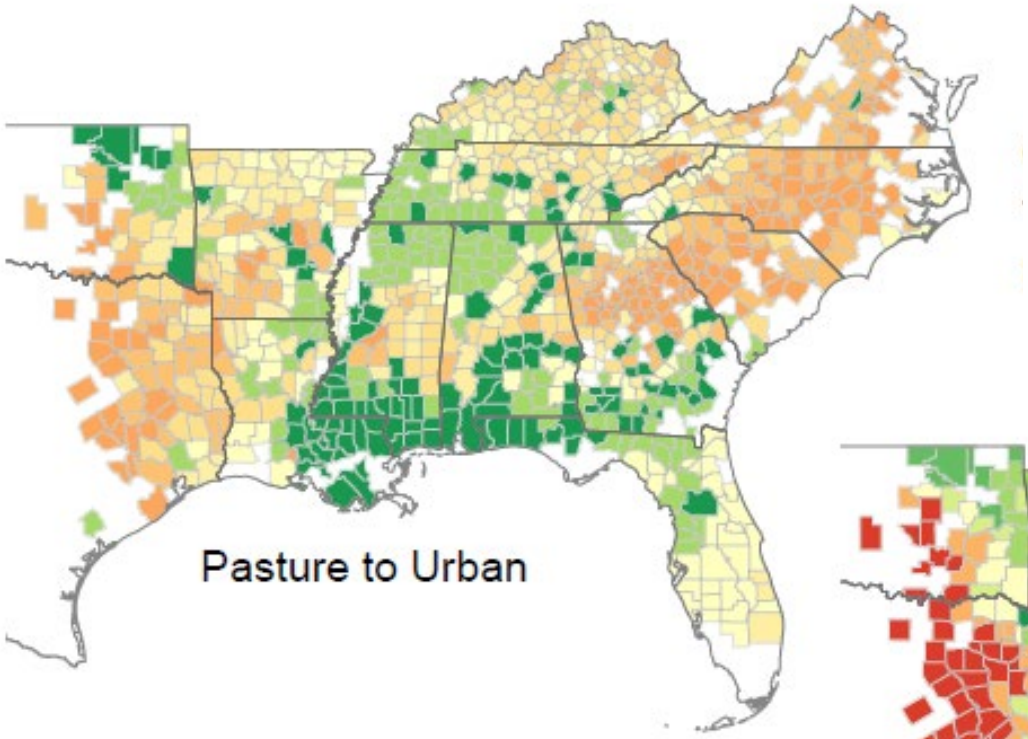



Yellow → No Impact

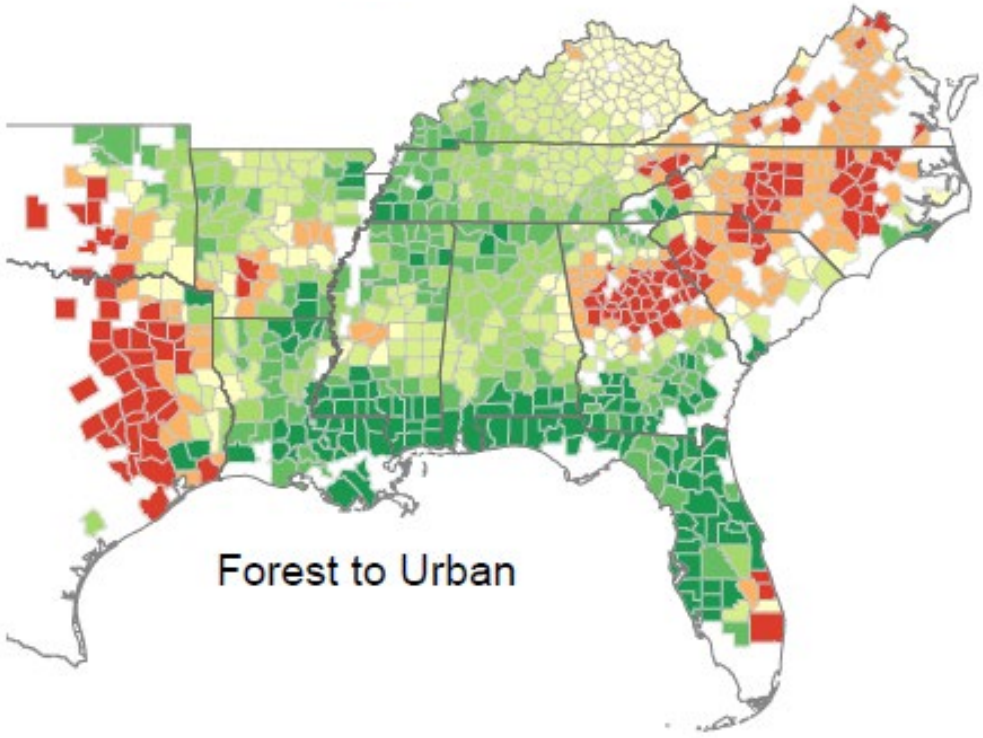
Red → Less Likely

Green → More Likely

# Urban growth slows or accelerates under climate change; continues to expand



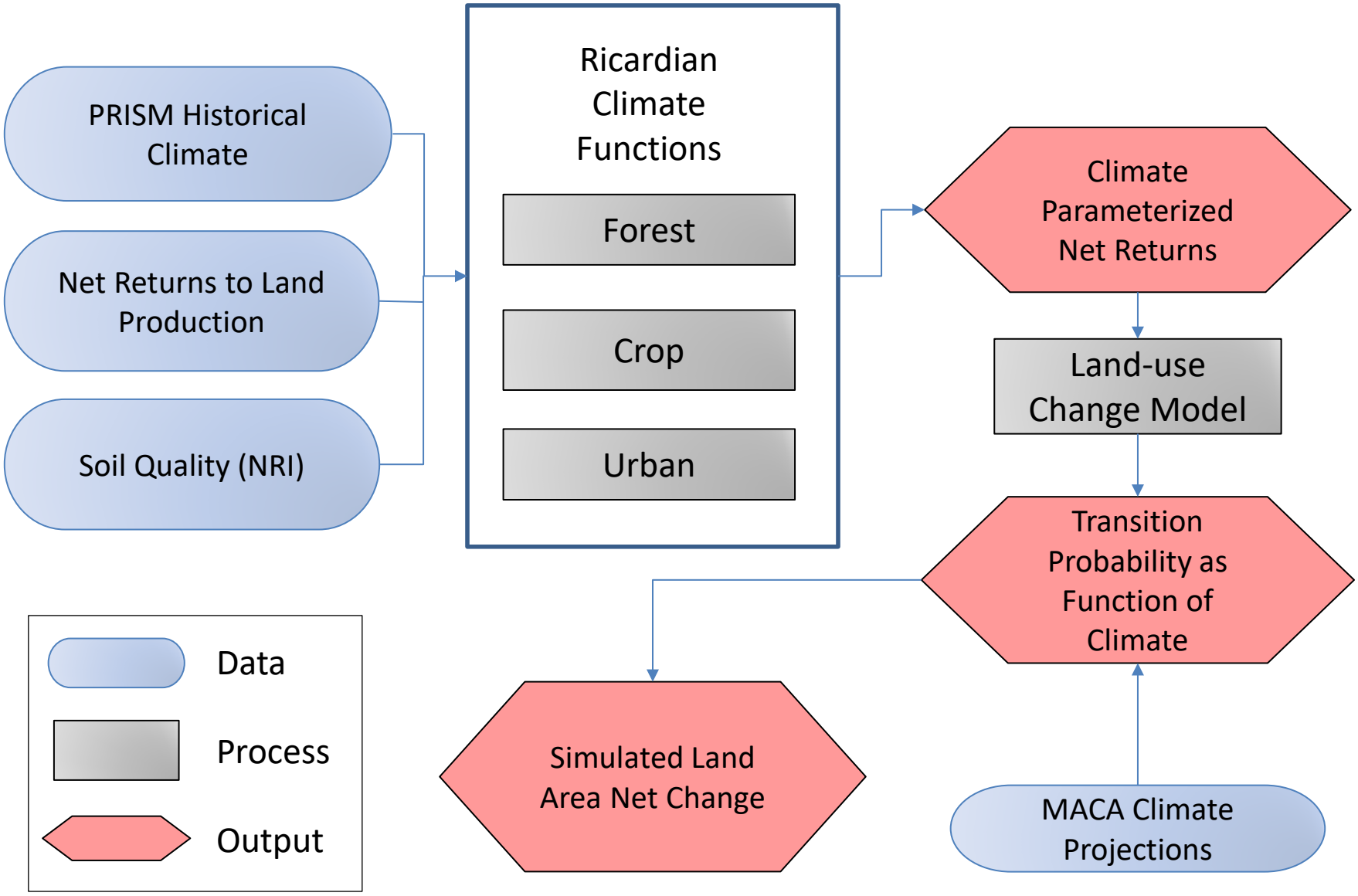

**Change in Transition Probability**




Yellow → No Impact

Red → Less Likely

Green → More Likely

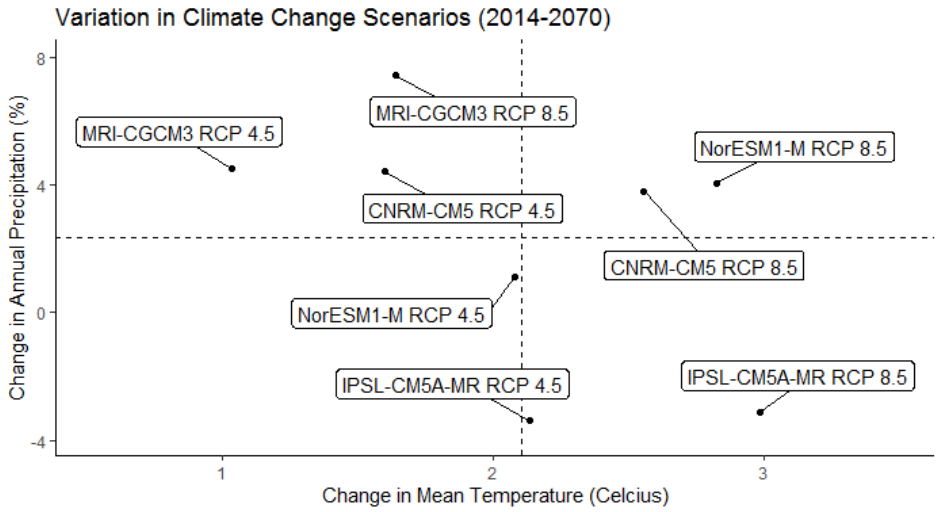

PRISM Historical Climate
Net Returns to Land Production
Soil Quality (NRI)
Ricardian Climate Functions
Forest
Crop
Urban
Climate Parameterized Net Returns
Land-use Change Model
Transition Probability as Function of Climate
Simulated Land Area Net Change
MACA Climate Projections
Data
Process
Output

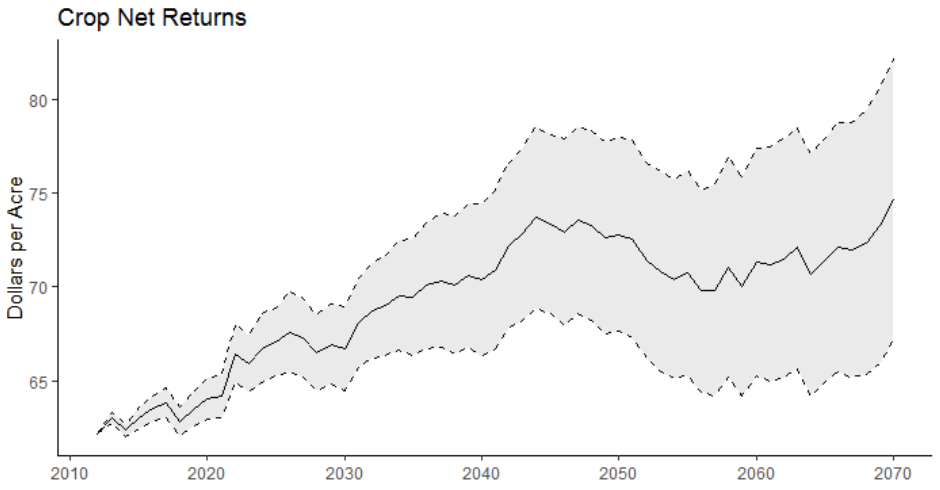
# Landscape Simulation

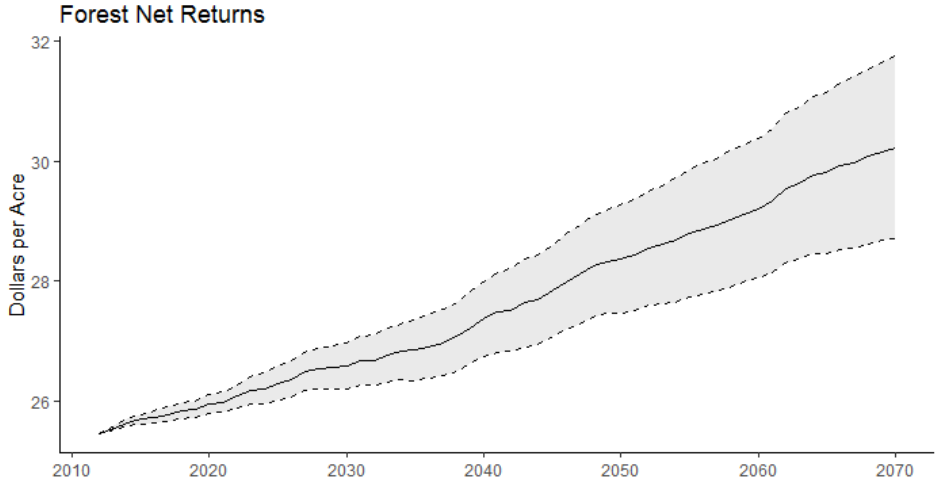
- Start with the observed landscape in 2012
- Calculate net return path for each land system based on climate change scenario
- Predict probability of conversation for each starting land use through end of scenario
- Employ discrete time Markov chain at two-year time steps
- Krinsky-Robb approach used to simulate confidence intervals for full set of projections

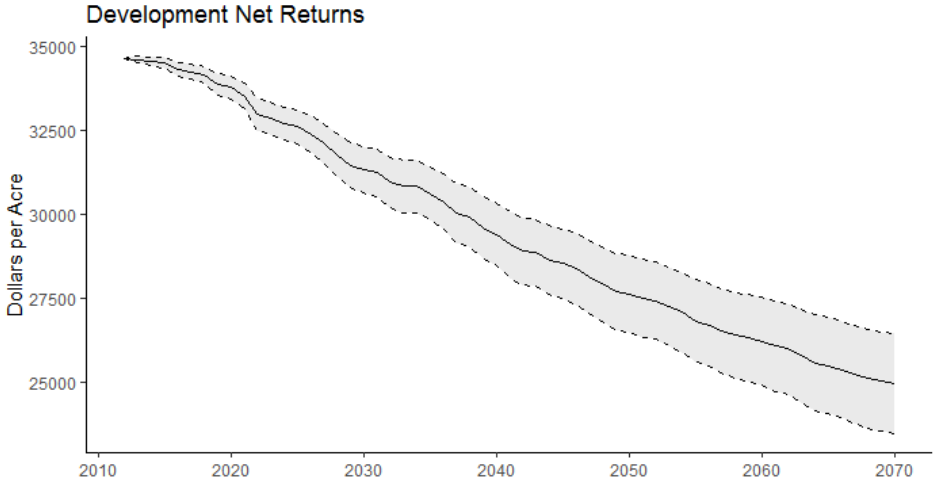
# Projecting Net Returns - Mean Climate Change

## Capturing parameter uncertainty



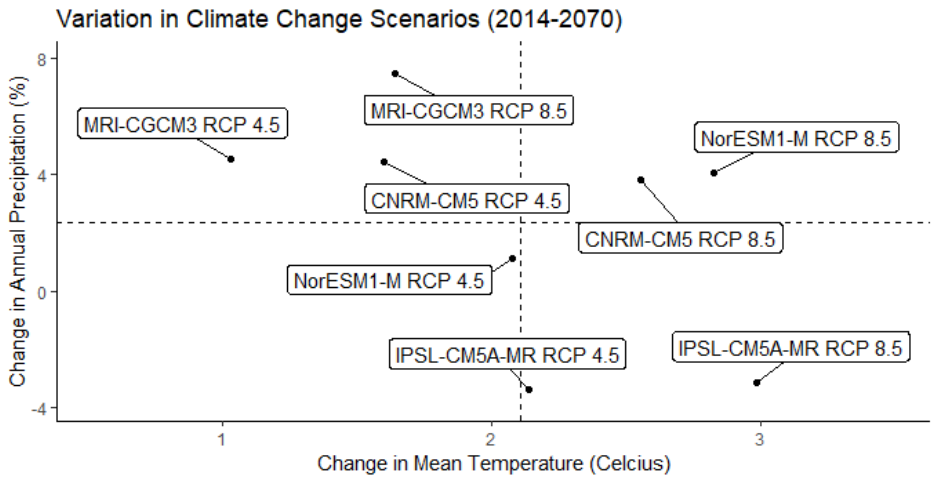



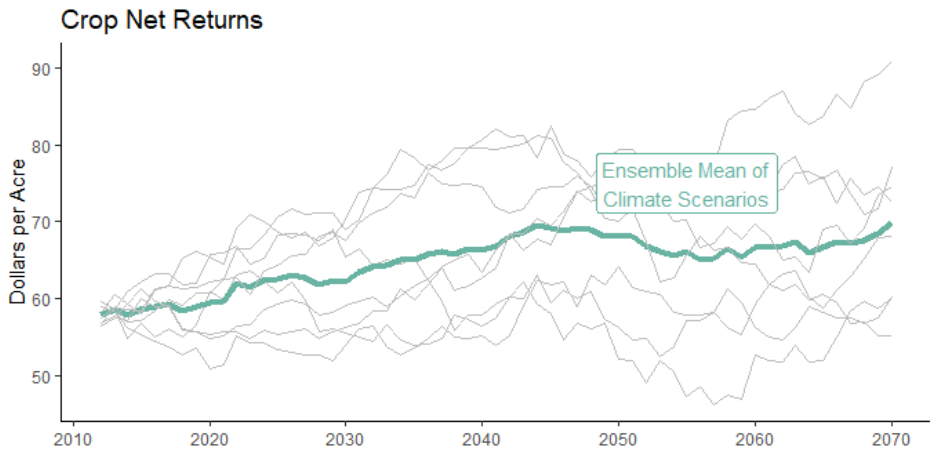



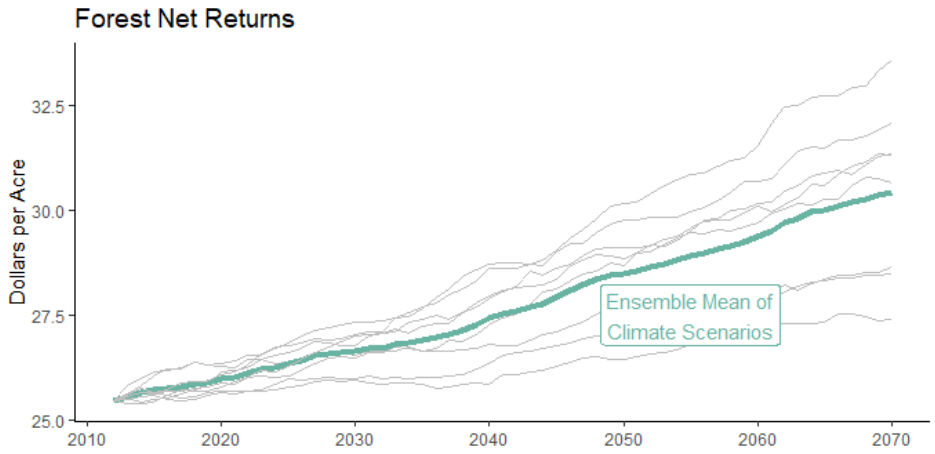



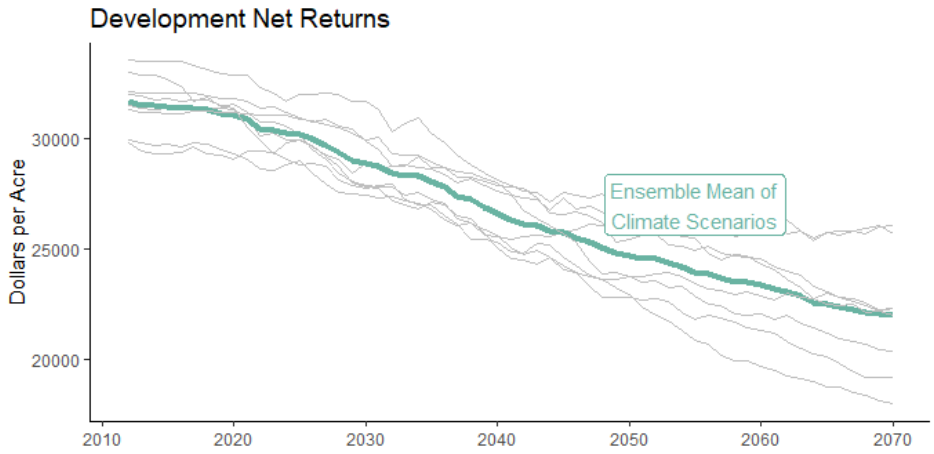
# Projecting Net Returns - Alternative Climate Projections

## Capturing climate model uncertainty



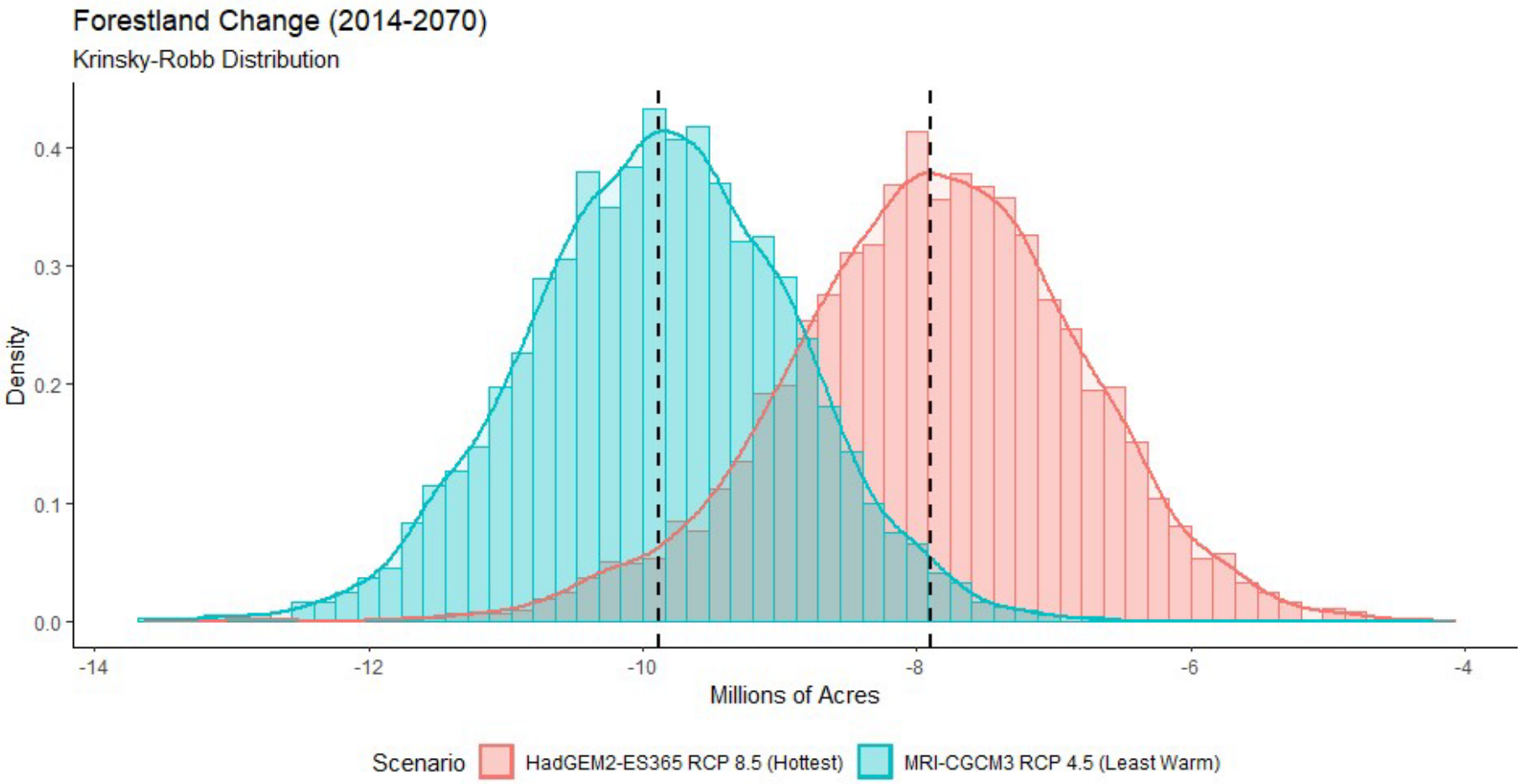



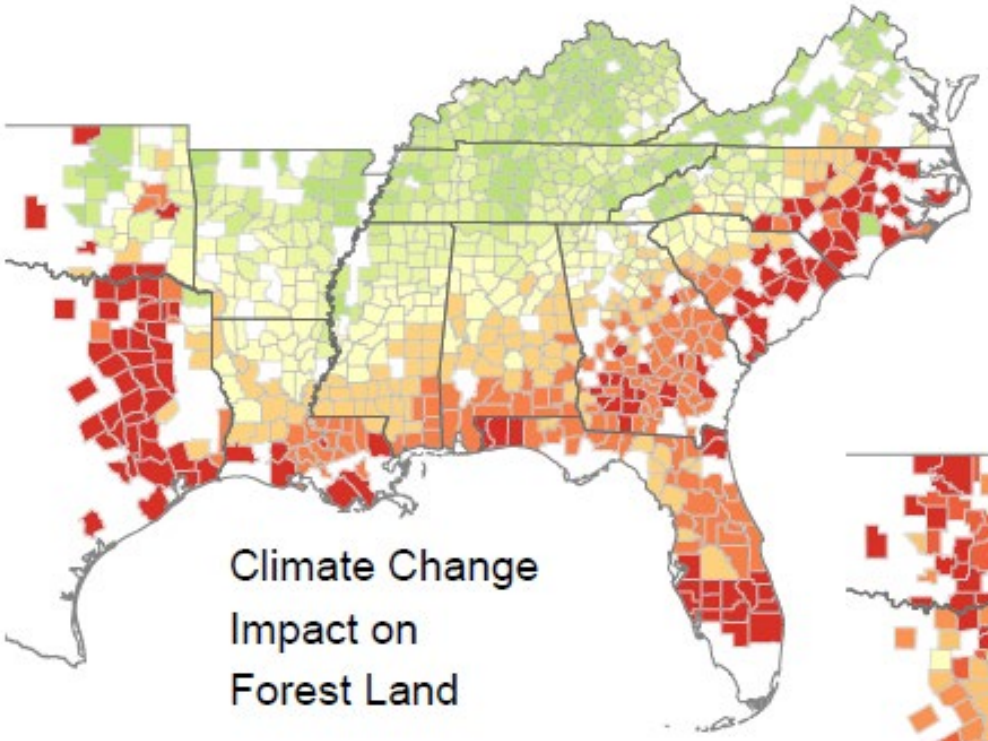



# Projecting Land-Use Change

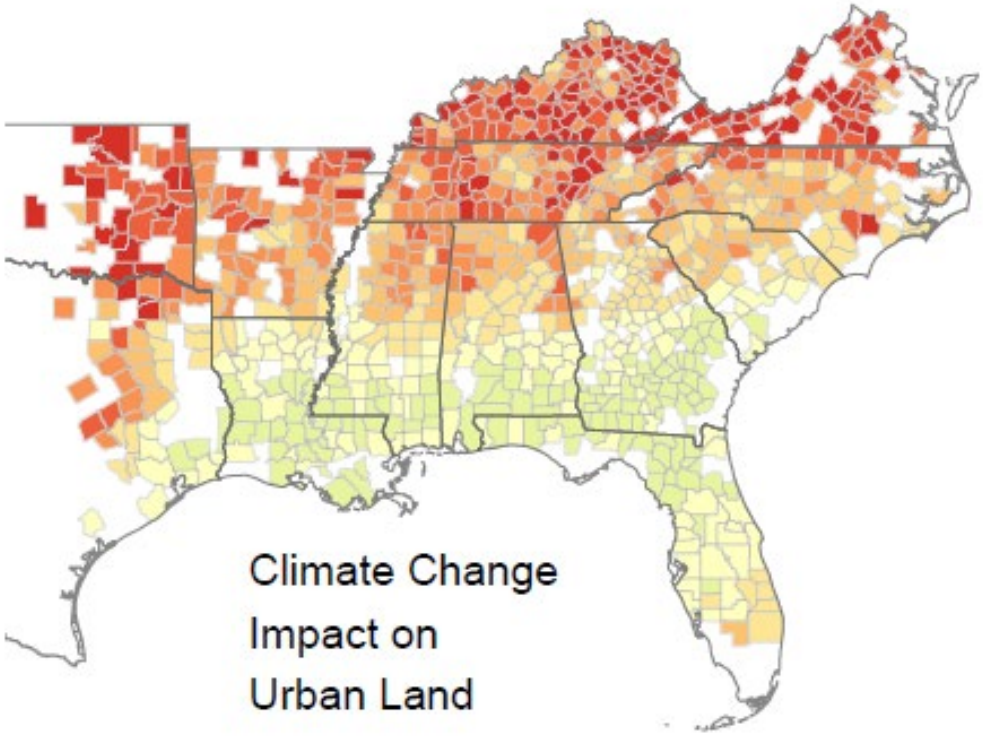
## Capturing climate model and parameter uncertainty



# Potential for tradeoffs between forest and urban land




**Change in Acres**



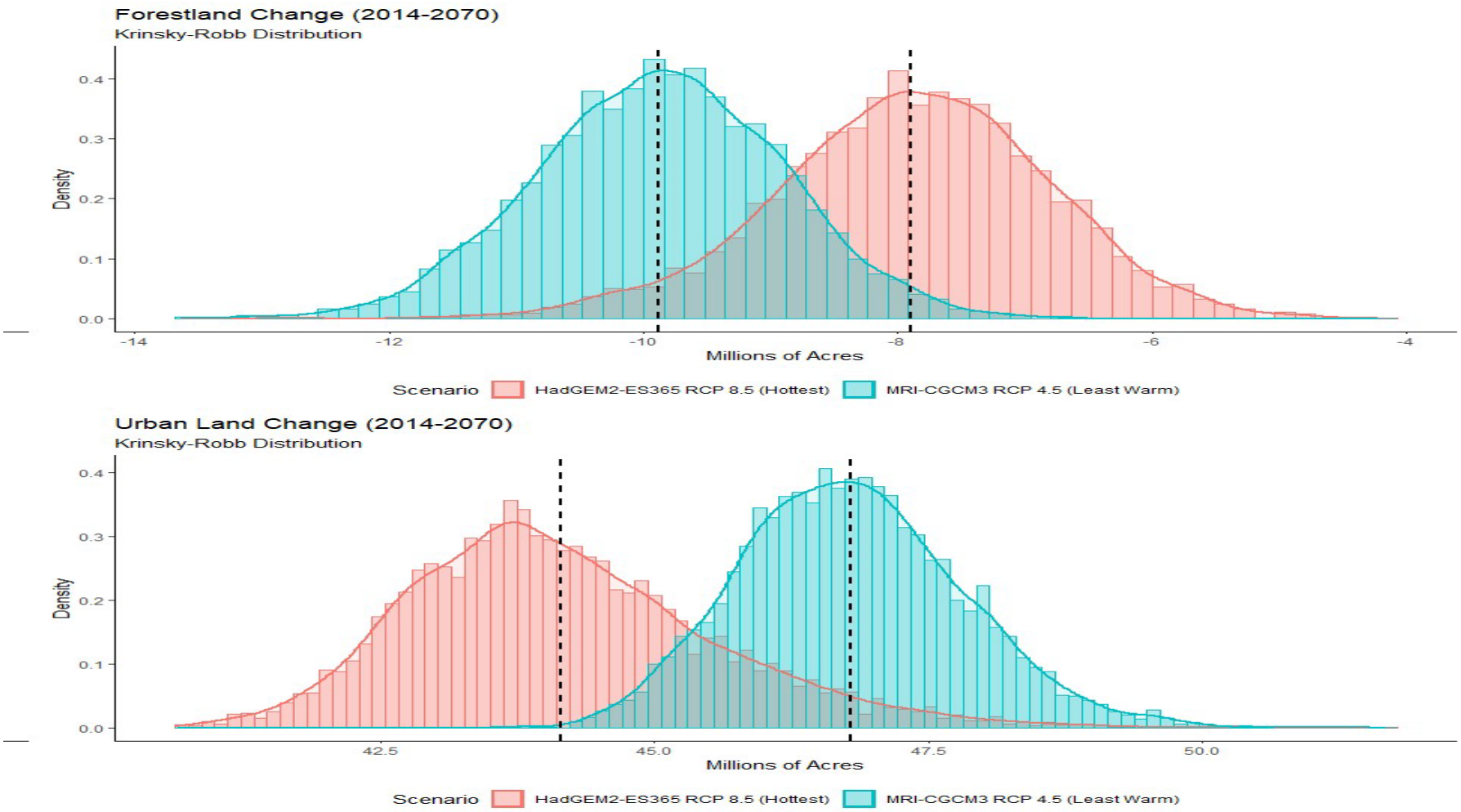

Yellow → No Net Change

Red → Less Acres

Green → More Acres

# Projecting Land-Use Change

## Capturing climate model and parameter uncertainty



# Climate Model Uncertainty

- We employ the Kolmogorov-Smirnov (KS) test to compare the distribution of land-use change outcomes
  - 26 out of 28 tests show that the result is statistically different between climate models
  - Direction of impacts are clear and significant
  - Magnitude differences are modest in aggregate;
    - Conclusion: For this study, the choice of baseline climate change scenario makes little difference
    - Caveat: We do not account for climate extremes arising from alternative climate models

# Limitations and Opportunities

- **Static Expectations Assumption**
  - Are landowners forward thinking with respect to climate change?
- **The impact of land-use change on commodity prices**
  - We model the impact of prices and value on land-use change, but what about price feedbacks?

# Conclusion

- **Linking climate change to land-use change**
  - Model implicitly accounts for management adaptation within each land-use system
  - Econometric evidence of how future landscape may be determined by climate change
- **Broad framework is flexible**
  - Evaluate changes to other drivers of land value including tax and subsidy policies
  - Analyze the quantity and quality of ecosystem goods and services resulting from forest area changes