NC STATE UNIVERSITY

Impacts of forest carbon offset markets on industrial pine pulpwood markets in the southern U.S. under alternative Forest Sector Pathways

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SOFAC Annual Meeting

Durham, NC

8/9/2022

Presentation Outline

- Background on Forest Carbon Offsets and "Additionality"
- Conceptual framework
- SRTS Review – Competitive Equilibrium and Goal Program
- SRTS Scenario Design
  - Illustrative case (AAEA working paper)
  - Forest Sector Pathways w/ varying degrees of offset market activity
- SRTS Projections (Results)
  - Offset broker's reaction curve to a change in prices

Forest Carbon Offset Projects in the South

- Long-term contracts:
  - CARB, ACR
- Short-term contracts:
  - NCX
  - SkyHarvest.
- Jan. 2022 NCX auction
  - 1,800 Landowners
  - 2 million acres
  - 15x increase over the Jan. 2021 auction

Jan. 2022 NCX Auction

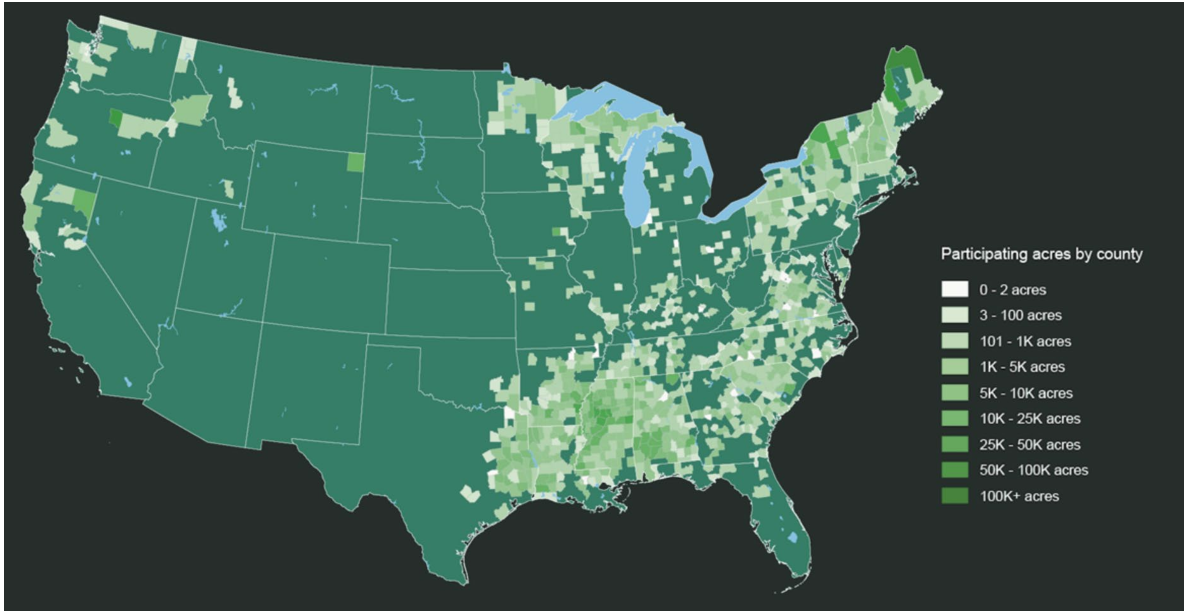


Image source: https://ncx.com/learning-hub/ncxs-latest-forest-carbon-program-results-demonstrate-growth-across-39-u-s-states/

Long-term Offset Projects

- Example: CARB program ACR209
  - Finite Carbon – Weyerhaeuser Co. IFM 1
  - Commitment to constrain harvest scheduling such that "no more than 40% of the project area is in age classes less than 20 years old."
  - Baseline Carbon stocks of 50.04 tCO_2e/ac.
  - Project site contains:
    - loblolly pine (>9" DBH by age 20)
    - shortleaf pine (>9" DBH by age 20)
    - red oak (<11" DBH by age 20)
    - white oak (<11" DBH by age 20)

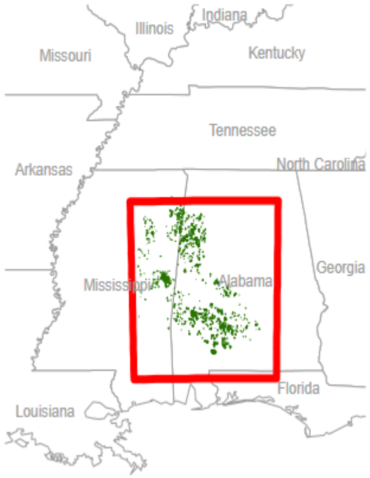
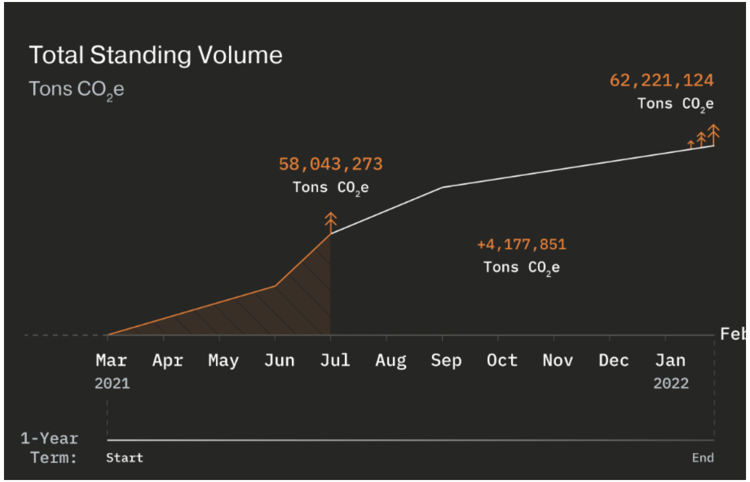


Image source: American Carbon Registry

Short Term Offset Projects

- Expanding market for forest carbon offsets in the U.S.
- New carbon markets have emerged that target "deferred harvests"
    - Compensation for ***temporary carbon storage***



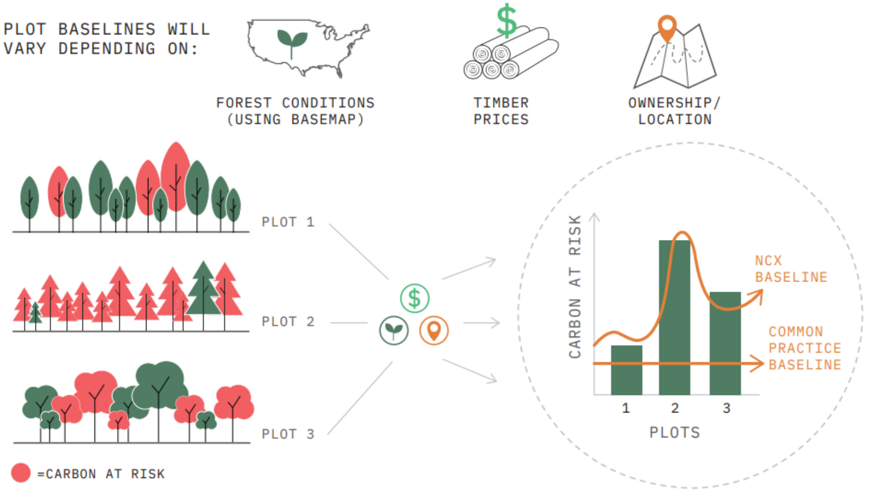
Source: ncx.com

Short-Term Offset Projects

- Example: NCX (short-term agreements & "Carbon-at-risk" calculations)

r as harvest intensity expressed as a proportion

FIGURE 1. Integrating ecological and social data to estimate "carbon at risk".



$$r = \alpha(\gamma + (1-\gamma) \times f(\mu, \phi))$$

where,

Harvest occurrence is modeled as

$$\alpha \sim A_X{*}(V_{T0} + V_{T1} + C_{ABG} + D_M + S + D_R + NWOS + (V_{T0} + V_{T1} + C_{ABG} + D_M + S + D_R + NWOS \mid O))$$

Total harvest decision is modeled as

$$\gamma \sim C_{ABG} + (C_{ABG} \mid O{:}F_C)$$

Partial harvest intensity is modeled as

$$f(\mu, \phi) \sim V_{T0} + V_{T1} + C_{ABG} + (V_{T0} + V_{T1} + C_{ABG} \mid O{:}F)$$

"Carbon-at-risk" is a function of $r * P_H$

Figure source: *NCX - Our Baseline model of harvesting behavior: How NCX uses forest inventory, satellite, and market data to predict "business as usual"*

Concerns over "Additionality"

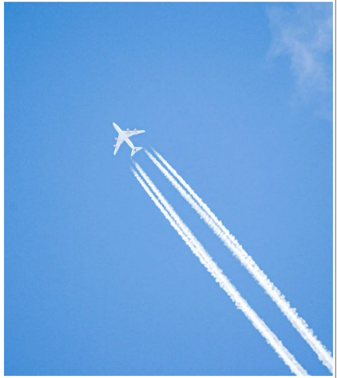
- "Additionality" – carbon stored beyond "business-as-usual" management conditions.
- Failure to achieve additionality threatens offset market stability/credibility.

The New York Times

Do Airline Climate Offsets Really Work? Here's the Good News, and the Bad.

Carbon credits could eventually play an important role in fighting climate change, but right now a few dollars' worth won't change much.

Give this article 38



ouse gas emissions in one place by funding emissions reductions or carbon removal somewhere

By Maggie Astor

May 18, 2022

Bloomberg
US Edition

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Green
Finance

This Timber Company Sold Millions of Dollars of Useless Carbon Offsets

Now Lyme Timber CEO Jim Hourdequin wants to fix a broken syste
market that actually helps slow climate change.

Hourdequin near the Lyme Timber office in L'Anse, Mich. *Photographer: Brian Lesteberg for Bloomberg Green*

By Ben Elgin
March 17, 2022, 5:00 AM EDT

The Economist

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Offset markets struggle in the face of surging commodity prices

Prices of carbon offsets are too low

Getty Images

May 19th 2022

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Concerns over "Additionality"

- Over-crediting problems
  - CARB program found to have over-credited 30 million tCO_2e from Jan. of 2004 to Sept. of 2020 (29.4% of credits in their sample).
  - These excess credits were valued at ~$410 million (~15.8% of the total value of credits in the sample).

DOI: 10.1111/gcb.15943

Global Change Biology WILEY

PRIMARY RESEARCH ARTICLE

Systematic over-crediting in California's forest carbon offsets program

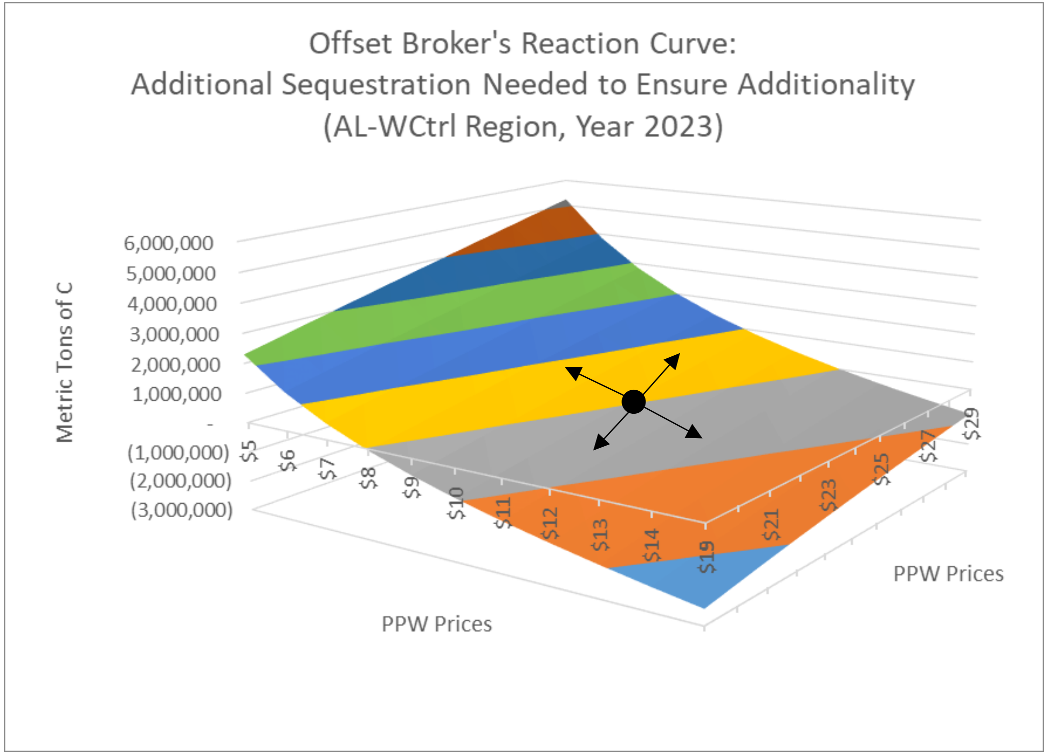
Grayson Badgley[1,2] | Jeremy Freeman[3] | Joseph J. Hamman[3,4] | Barbara Haya[5] | Anna T. Trugman[6] | William R. L. Anderegg[7] | Danny Cullenward[3,8]

What Role Can Economic Models Play?

- Additionality is a ***market concept***
- ***Additionality thresholds are endogenous to market adjustments and existing carbon offset investments***
  - ➢Offset auctions themselves impact roundwood harvests and stumpage prices, so attempts to account for additionality when approving offset sellers don't do two critical things:
    1. Use post-auction roundwood prices to determine "Carbon-at-Risk"
    2. Re-assess landowners' harvest probability after unforeseen demand shocks.
- Q: By how much do offset markets need to increase sequestration in order to ensure additionality after a change in prices?
  - Is this amount sensitive to changes in southwide harvest deferrals?

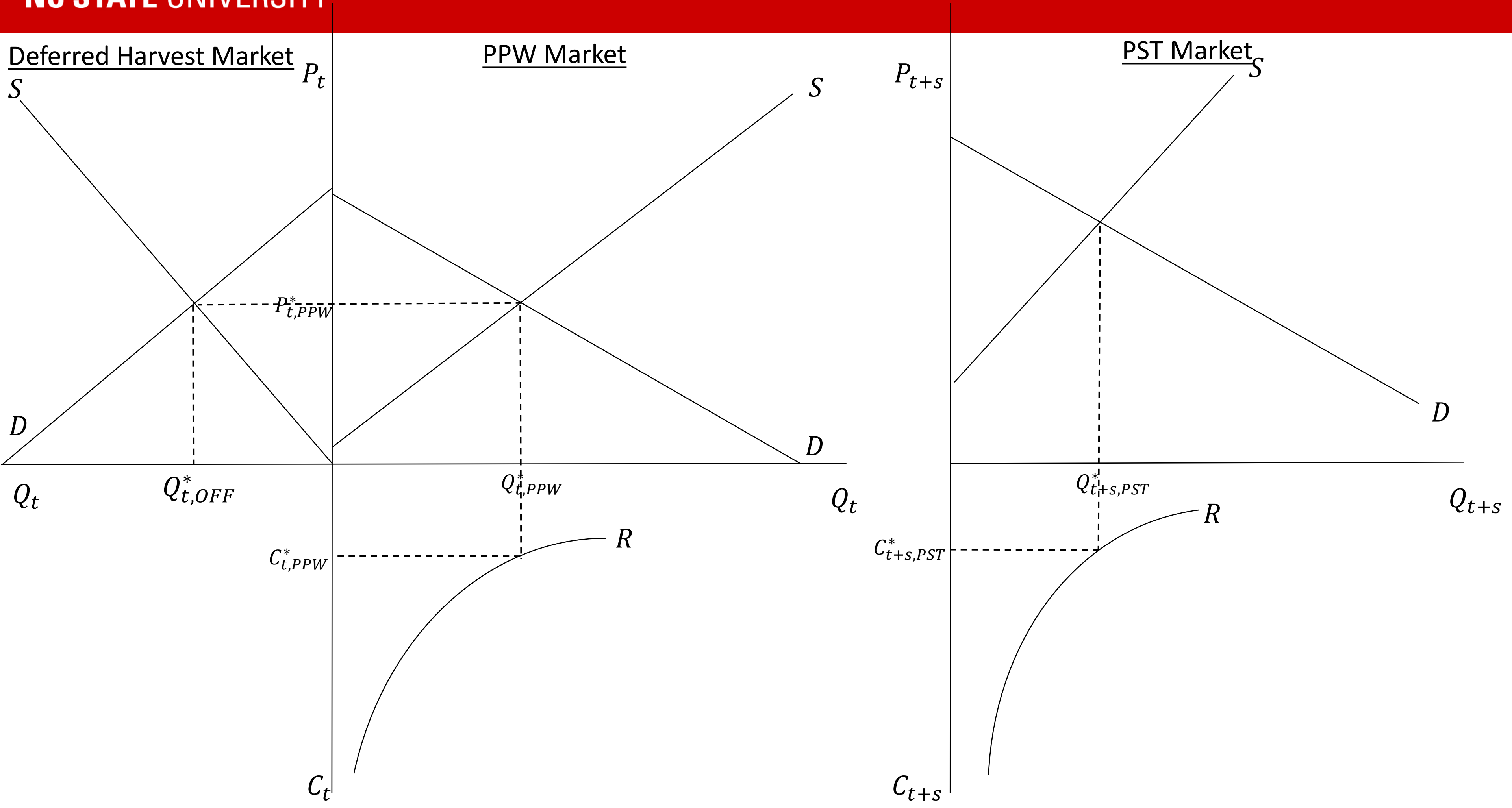
What Role Can Economic Models Play?

- Assume the current price state is:
  - PPW - $10/ton
  - PST - $24/ton
  - HPW - $11/ton
  - HST - $33/ton

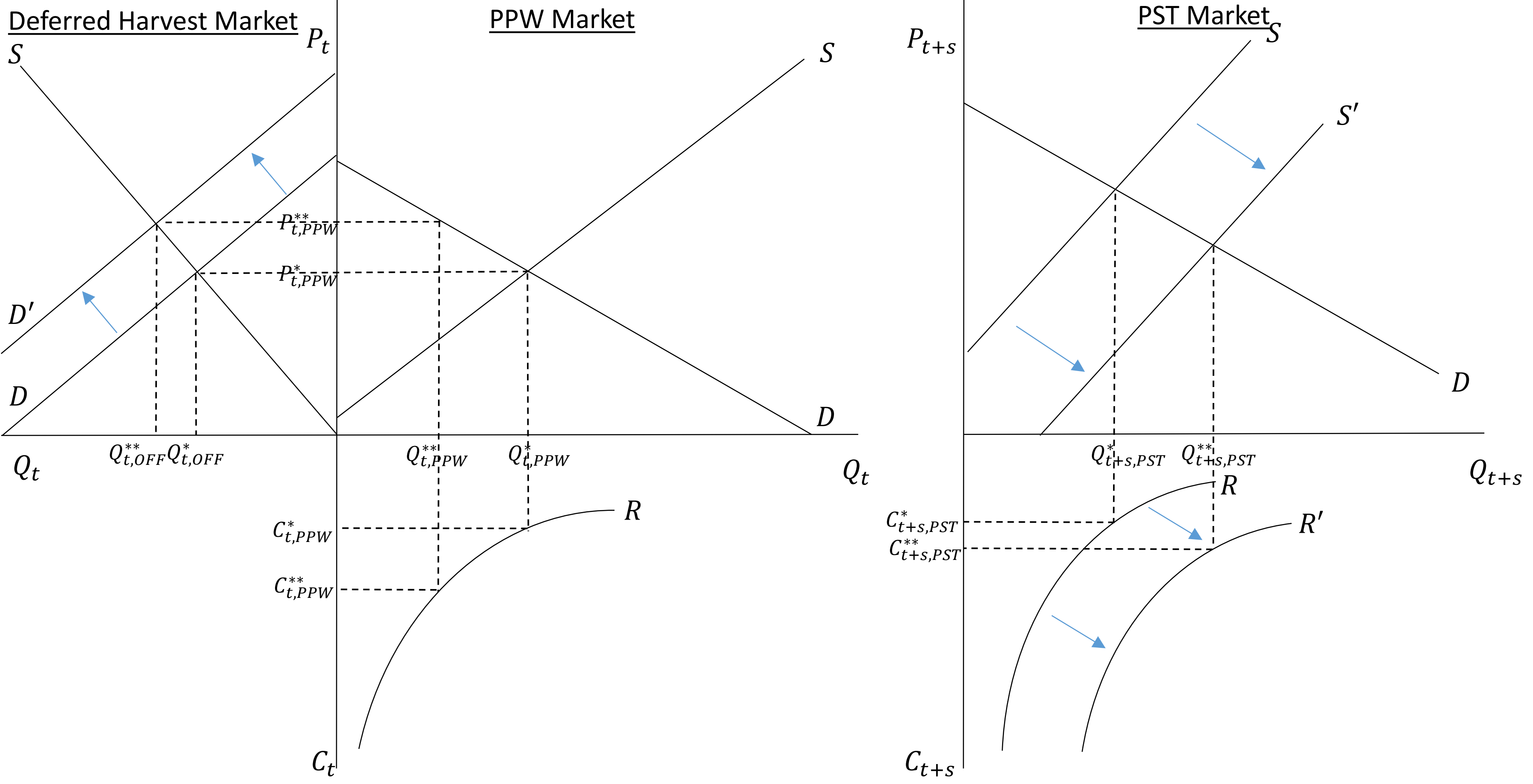


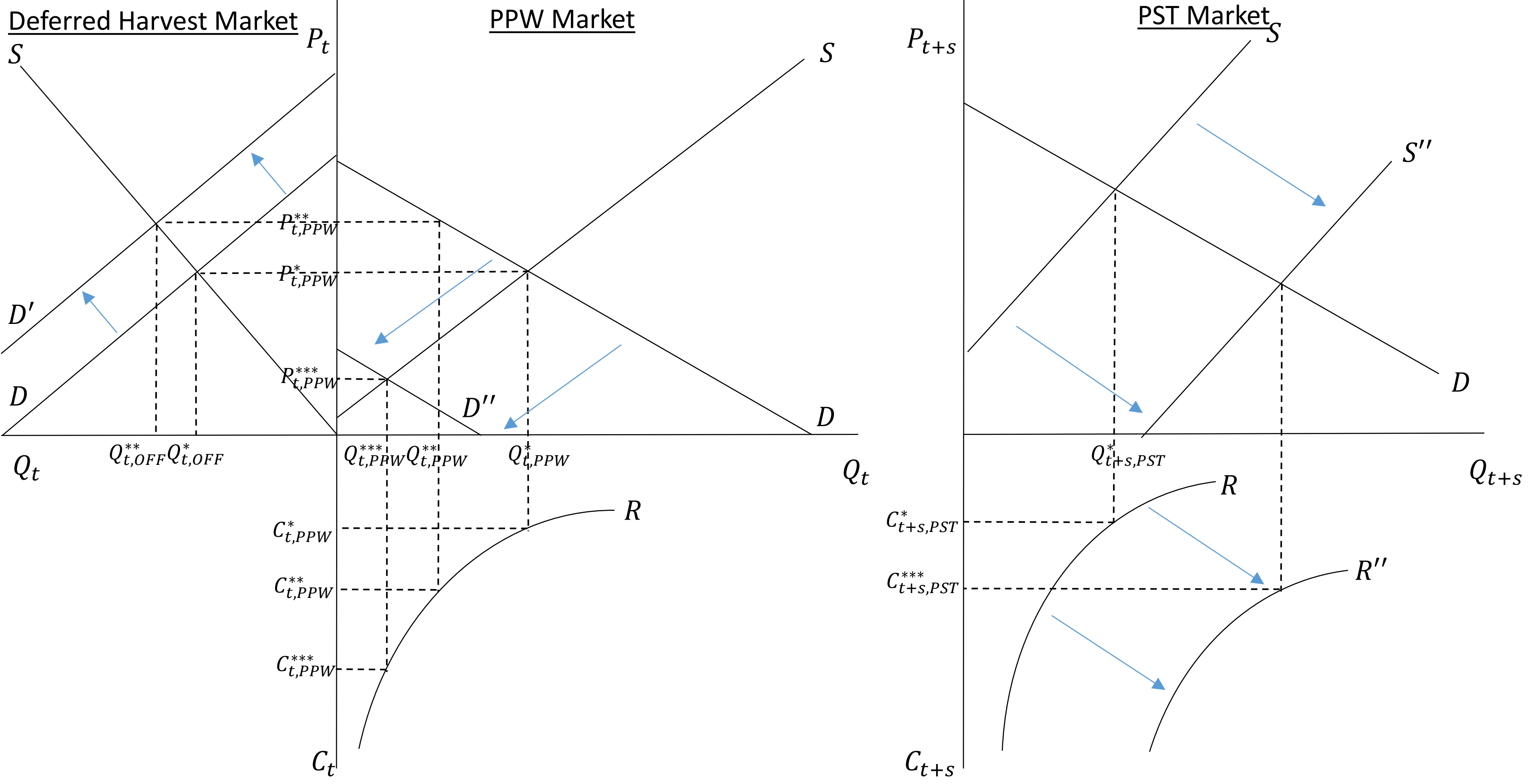
Conceptual Framework

Multi-product markets from pine systems, deferred harvests, and carbon sequestration



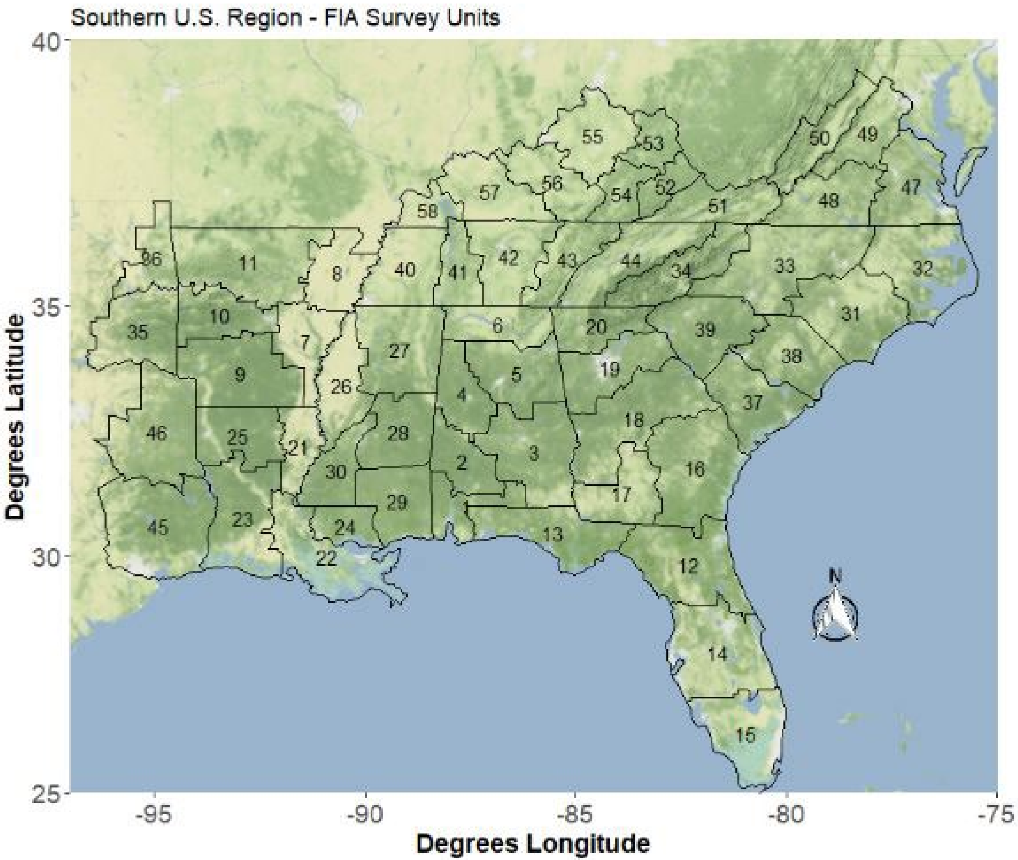
Deferred Harvest Market
PPW Market
PST Market
P_t
P_{t+s}
S
S
S
D
D
D
$P^*_{t,PPW}$
Q_t
$Q^*_{t,OFF}$
$Q^*_{t,PPW}$
Q_t
$Q^*_{t+s,PST}$
Q_{t+s}
R
R
$C^*_{t,PPW}$
$C^*_{t+s,PST}$
C_t
C_{t+s}


Deferred Harvest Market
PPW Market
PST Market
P_t
S
S
D'
D
D
$P^{**}_{t,PPW}$
$P^{*}_{t,PPW}$
Q_t
$Q^{**}_{t,OFF}$ $Q^{*}_{t,OFF}$
$Q^{**}_{t,PPW}$
$Q^{*}_{t,PPW}$
Q_t
$C^{*}_{t,PPW}$
$C^{**}_{t,PPW}$
R
C_t
P_{t+s}
S
S'
D
$Q^{*}_{t+s,PST}$ $Q^{**}_{t+s,PST}$
Q_{t+s}
R
R'
$C^{*}_{t+s,PST}$
$C^{**}_{t+s,PST}$
C_{t+s}


Deferred Harvest Market
PPW Market
PST Market
S
D'
D
P_t
Q_t
$P^{**}_{t,PPW}$
$P^{*}_{t,PPW}$
$P^{***}_{t,PPW}$
$Q^{**}_{t,OFF}$
$Q^{*}_{t,OFF}$
$Q^{***}_{t,PPW}$
$Q^{**}_{t,PPW}$
$Q^{*}_{t,PPW}$
D''
R
$C^{*}_{t,PPW}$
$C^{**}_{t,PPW}$
$C^{***}_{t,PPW}$
C_t
P_{t+s}
Q_{t+s}
S''
$Q^{*}_{t+s,PST}$
R''
$C^{*}_{t+s,PST}$
$C^{***}_{t+s,PST}$
C_{t+s}

Methods:

- Bio-economic model of timber markets in the US South
  - Sub-Regional Timber Supply Model (SRTS)
  - Captures inter-dependencies between markets, forest growth/harvest dynamics and land use change



Roundwood Product Definitions (.PRD)

Product Type	Size Class (DBH)	Percent of harvest available as pulpwood	ϵ_j	$\gamma_{corp,j}$ $(\tau_{corp,j})$	$\gamma_{corp,j}$ $(\tau_{noncorp,j})$
PPW	5”-9”	100%	0.65	0.45 (0.85)	0.30 (0.80)
PST	≥9”	30%	0.50	0.51 (0.66)	0.32 (0.70)
HPW	5-11”	100%	0.35	0.54 (0.61)	0.33 (0.71)
HST	≥ 11"	35%	0.40	0.52 (0.61)	0.31 (0.71)

SRTS Overview

- Partial equilibrium model of the southern US forest sector
- Dynamic supply defined by subregion (*i*), product type (*j*), ownership (*o*) and year (*t*)

Prices

$$Q^S_{iojt}(P_{jt}, V_{iojt}) = \alpha P_{jt}^{\gamma_{oj}} V_{iojt}^{\tau_{oj}}$$

$$Q^D_{jt}(P_{jt}) = \beta P_{jt}^{\epsilon_j}$$

$$\sum_i \sum_o Q^S_{iojt}(P_{jt}, V_{iojt}) = Q^D_{jt}$$

Growing stock volume

Review: SRTS Goal Programming Problem

$$\underset{\{x_{gm},\mu_j,\nu_j,s^1_{gm},s^2_{gm}\}}{\text{minimize:}} \sum_{j=1}^{J} W_j(\mu_j + \nu_j) + \sum_{g=3}^{11}\sum_{m=1}^{5} Z_{gm}\left(s^1_{gm} + s^2_{gm}\right)$$

Subject to:

$$\sum_{g=3}^{11}\sum_{m=1}^{5} c_{jgm}x_{gm} + \mu_j - \nu_j = Q_j^{S^*} \quad \forall j = 1, \dots, J$$

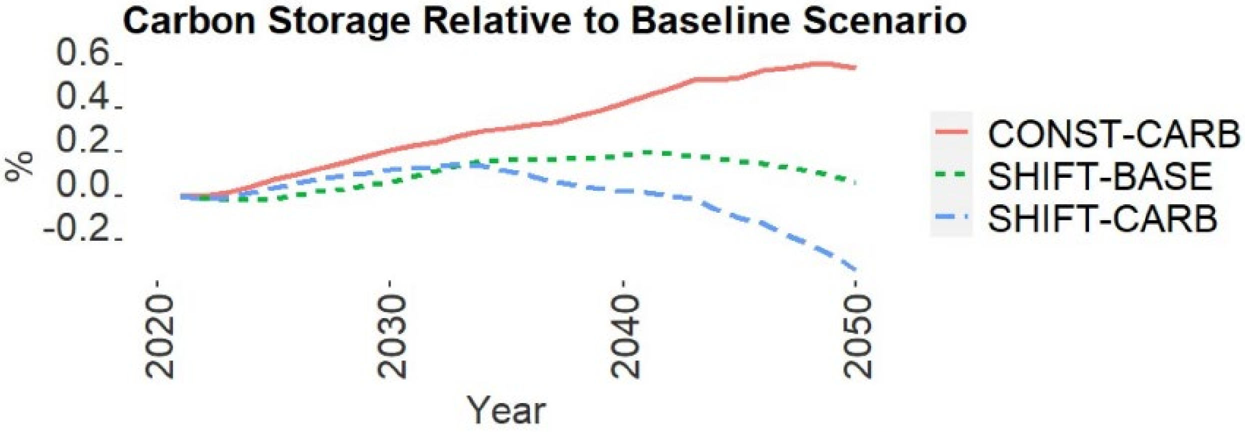
Volume of product *j* by management type and age class

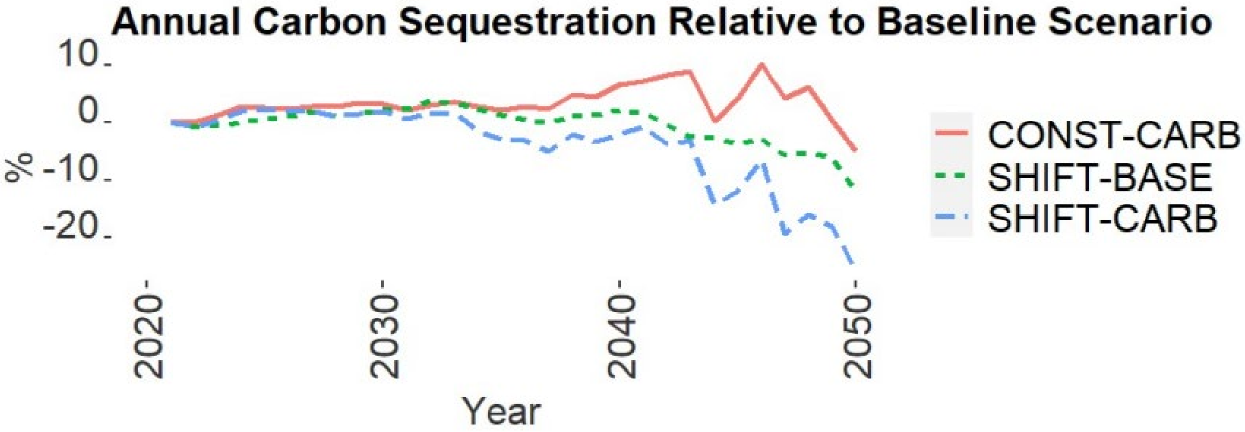
$$x_{gm} + s^1_{gm} - s^2_{gm} = \frac{Q^{S}_{gm,t-1}{}^{*}}{V_{gm,t-1}} \quad \forall g = 3, \dots, 11 \,\&\, \forall m = 1, \dots, 5$$

$$\mu_j \geq 0, \eta_j \geq 0, s^1_{gm} \geq 0, s^2_{gm} \geq 0, x_{gm} \geq 0$$

Representation of Deferred Harvest in SRTS (.PW file construction for Illustrative case)

- No Offset MKT w/ Constant PPW Demand (Baseline scenario: “CONST-BASE”):
  - $W_{PPW} = 1{,}000; W_{PST} = 1{,}000$
- Offset MKT Activity w/ Constant PPW Demand (“CONST-CARB”):
  - $W_{PPW} = 1; W_{PST} = 100{,}000$
- No Offset MKT Activity w/ Falling PPW Demand of -3%/yr. (“SHIFT-BASE”):
  - $W_{PPW} = 1{,}000; W_{PST} = 1{,}000$
- Offset MKT Activity w/ Falling PPW Demand of -3%/yr. (“SHIFT-CARB”):
  - $W_{PPW} = 1; W_{PST} = 100{,}000$


Carbon Storage Relative to Baseline Scenario
0.6
0.4
0.2
0.0
-0.2
%
2020
2030
2040
2050
Year
CONST-CARB
SHIFT-BASE
SHIFT-CARB

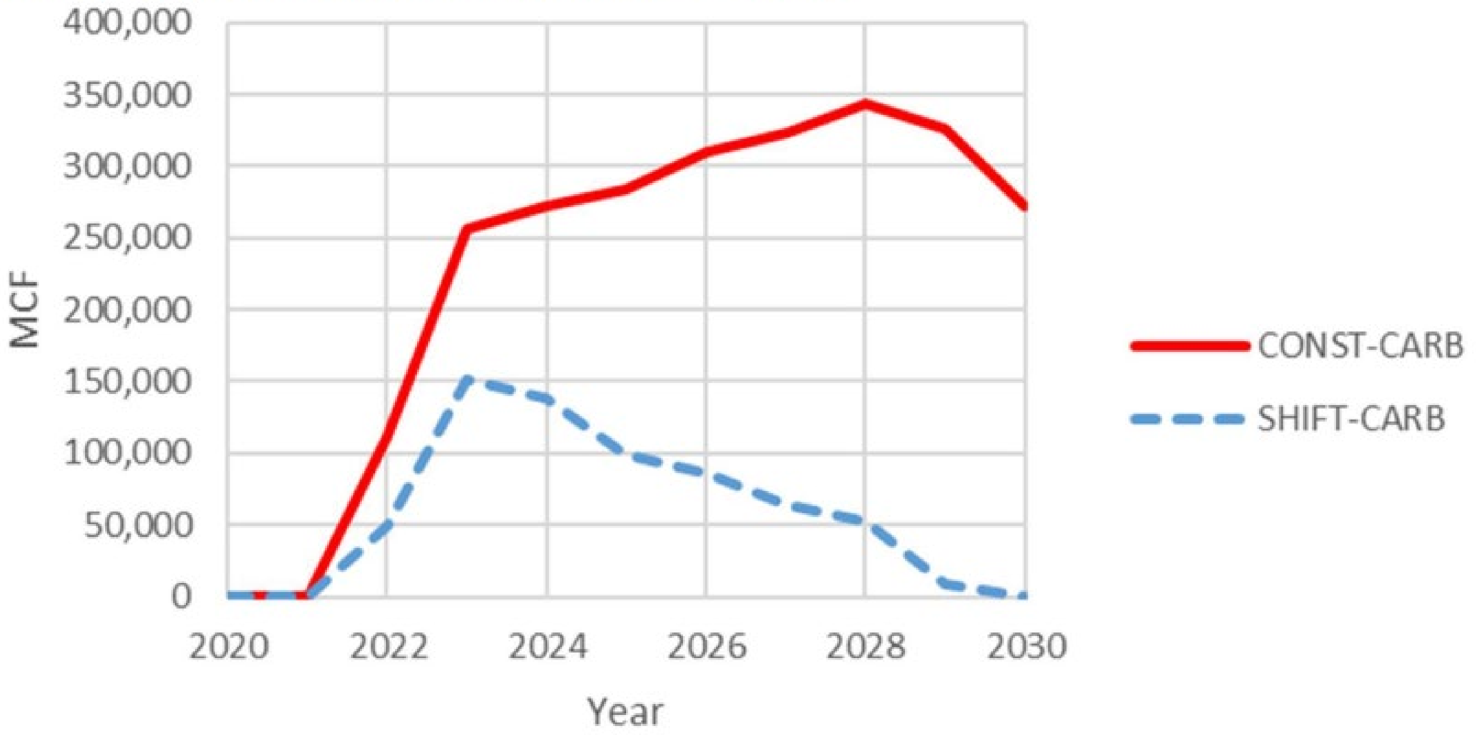

Annual Carbon Sequestration Relative to Baseline Scenario
10
0
-10
-20
%
2020
2030
2040
2050
Year
CONST-CARB
SHIFT-BASE
SHIFT-CARB

Percent of Harvest above or below the southwide competitive equilibrium

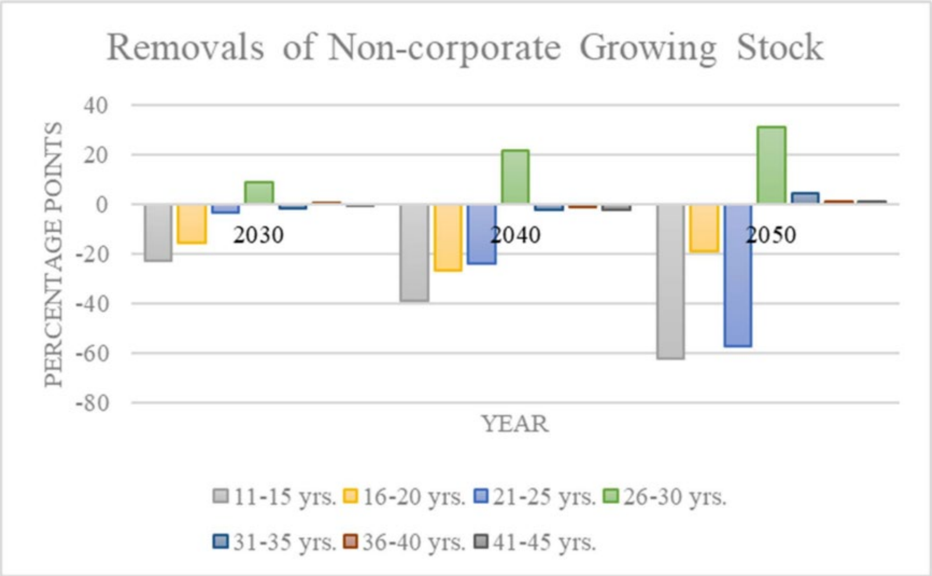
measure of disequilibrium in the industrial roundwood markets)

	2022	2024	2026	2028	2030
PPW Harvest					
CONST-BASE	+0.2%	+0.2%	+0.2%	+0.4%	+0.9%
CONST-CARB	-3.2%	-7.5%	-8.4%	-9.2%	-7.2%
SHIFT-BASE	+0.2%	+0.2%	+0.5%	+1.1%	+2.1%
SHIFT-CARB	-1.4%	-4.0%	-2.5%	-1.5%	+3.3%
PST Harvest					
CONST-BASE	+1.5%	+2.2%	+3.2%	+4.8%	+6.4%
CONST-CARB	+1.2%	+1.8%	+2.8%	+4.2%	+5.4%
SHIFT-BASE	+1.5%	+2.1%	+3.0%	+4.5%	+6.0%
SHIFT-CARB	+1.2%	+1.8%	+2.7%	+4.1%	+5.4%

Figure 7: Volume of pulpwood harvest deferred under a forest carbon offset program with constant and shifting demand scenarios (2020-2030)



Projected Pct. Point Diff in the effects of Offset MKT on removals of Pine Plantation Inventory by Age Class across constant and falling PPW demand scenarios



Key Takeaways at this point…

- Market conditions and carbon offset activity itself impacts carbon sequestration
- Deferred harvest contracts could continue to rely on empirical determinations of eligibility
- ***BUT…*** Markets matter & Path dependency matters
  - Additionality criteria need to reflect market dynamics
  - Additionality criteria need to reflect the effects of existing deferrals on future baseline carbon sequestration rates
  - *When informed by price dynamics*, "coarse regional averages", can still be useful for setting sequestration targets to avoid over-crediting problems.
    - Proof of concept to follow…

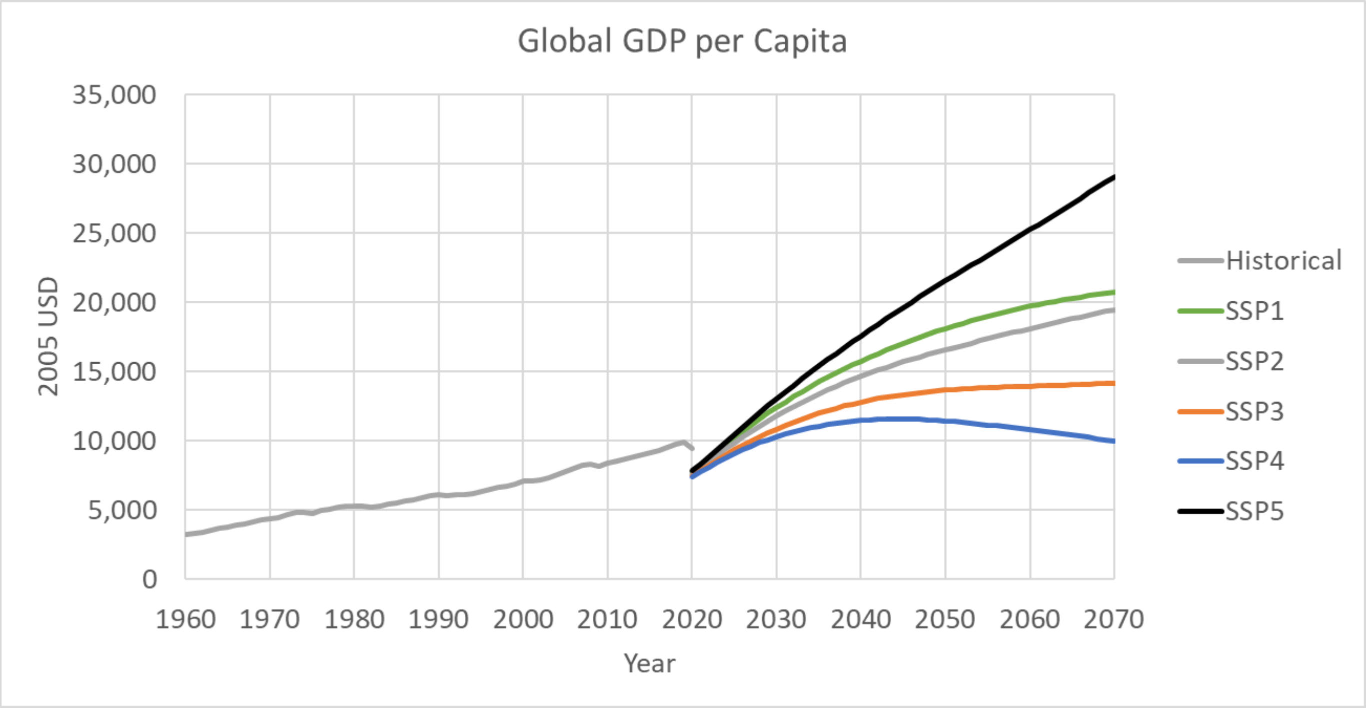
Alternative Scenario Design
(Forest Sector Pathways & SRTS Batch Mode)

Shared Socioeconomic Pathways (SSPs)

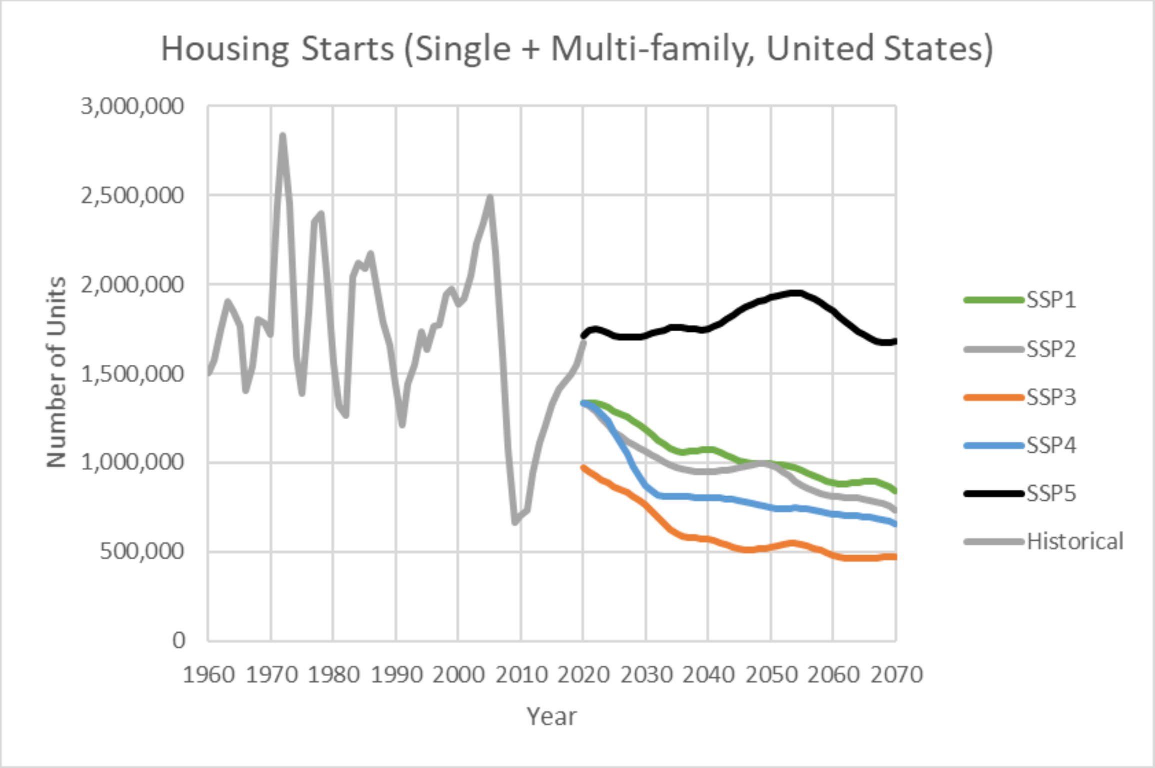
- 5 macroeconomic scenarios
  - SSP1 – "Sustainability" (greater utilization of renewable/cleaner energy, moderate economic growth)
  - SSP2 – "Middle-of-the-Road" (business-as-usual macro development, moderate economic growth)
  - SSP3 – "Regional Rivalry" (protectionism, limited international trade, low economic growth)
  - SSP4 – "Inequality" (income/wealth inequality, low to negative on economic growth)
  - SSP5 – "Fossil-fueled Development" (higher use of fossil-fuels, higher economic growth)

- Projections of exogenous macro conditions from the IIASA (SSP data from 2020-2070):
  - Real global GDP per capita
  - Income Inequality (U.S. Gini Index)
  - U.S. Housing starts (data courtesy of Dr. Jeff Prestemon, USFS)

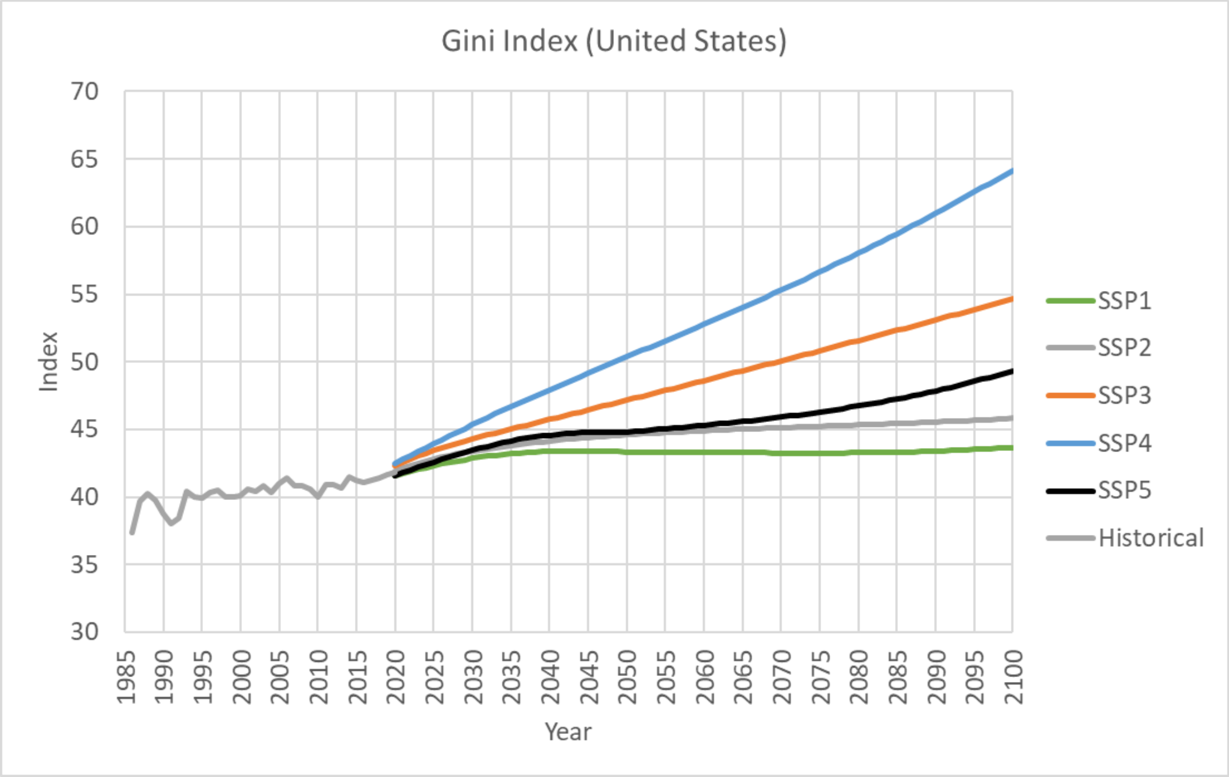
Global Real GDP per Capita
$(RGDPCAP_t)$



U.S. Housing Starts (Single + Multi-family) $(HOUST_t)$



U.S. Income Inequality ($GINI_t$)



Conditional roundwood consumption forecasts by product: Non-structural VAR model

$$\Delta \ln Q^D_{PPW,t} = \beta_{01} + \beta_{11}\Delta \ln GINI_t + \beta_{21}\Delta \ln HOUST_t + \beta_{31}\Delta \ln RGDPCAP_t + \sum_j \alpha_{j1}\Delta \ln Q^D_{j,t-1} + \theta_1 t + \varepsilon_{PPW,t}$$

$$\Delta \ln Q^D_{PST,t} = \beta_{03} + \beta_{13}\Delta \ln GINI_t + \beta_{23}\Delta \ln HOUST_t + \beta_{33}\Delta \ln RGDPCAP_t + \sum_j \alpha_{j3}\Delta \ln Q^D_{j,t-1} + \theta_3 t + \varepsilon_{PST,t}$$

$$\Delta \ln Q^D_{HPW,t} = \beta_{04} + \beta_{14}\Delta \ln GINI_t + \beta_{24}\Delta \ln HOUST_t + \beta_{34}\Delta \ln RGDPCAP_t + \sum_j \alpha_{j4}\Delta \ln Q^D_{j,t-1} + \theta_4 t + \varepsilon_{HPW,t}$$

$$\Delta \ln Q^D_{HST,t} = \beta_{05} + \beta_{15}\Delta \ln GINI_t + \beta_{25}\Delta \ln HOUST_t + \beta_{35}\Delta \ln RGDPCAP_t + \sum_j \alpha_{j5}\Delta \ln Q^D_{j,t-1} + \theta_5 t + \varepsilon_{HST,t}$$

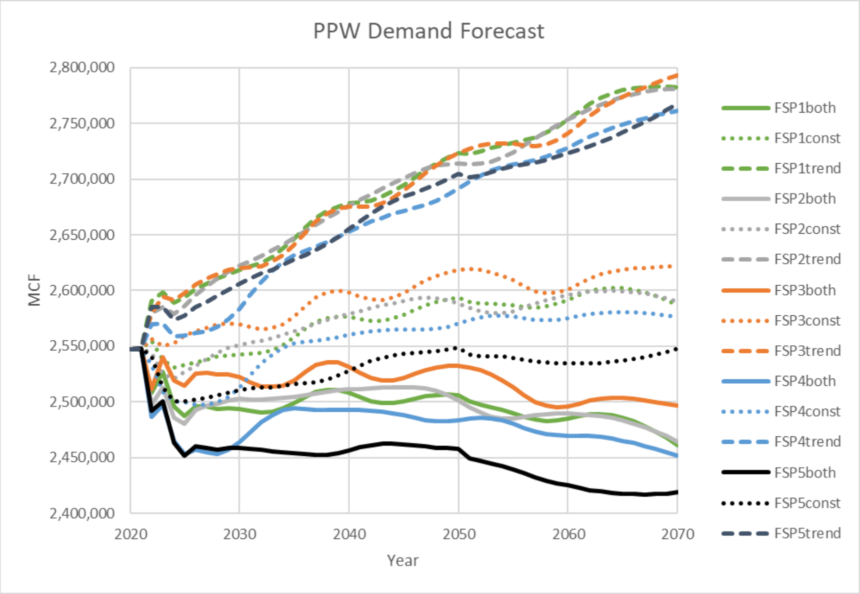
Non-structural VAR Model Results

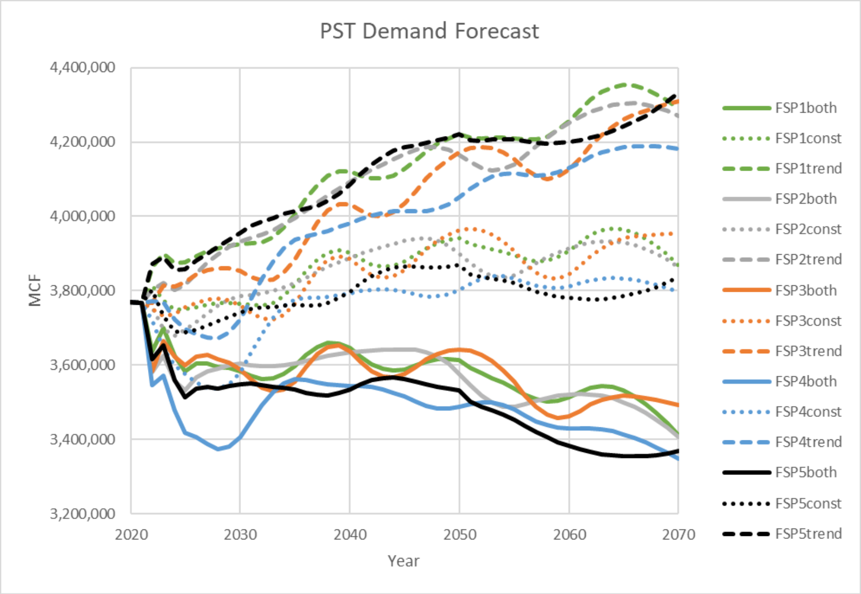
Nonstructural VAR Model Results (Annual Data, 1990-2020)

Equation:	$\Delta \ln Q^D_{PPW,t}$	$\Delta \ln Q^D_{PST,t}$	$\Delta \ln Q^D_{HPW,t}$	$\Delta \ln Q^D_{HST,t}$
constant	0.06	0.05	0.00	-0.06
	(0.10)	(0.09)	(0.07)	(0.06)
$\Delta \ln Q^D_{PPW,t-1}$	0.48	0.40	0.30	0.11
	(0.57)	(0.56)	(0.41)	(0.38)
$\Delta \ln Q^D_{PST,t-1}$	-0.57	-0.47	-0.75	0.24
	(1.01)	(1.00)	(0.72)	(0.68)
$\Delta \ln Q^D_{HPW,t-1}$	-0.03	0.17	0.05	-0.26
	(0.63)	(0.62)	(0.45)	(0.42)
$\Delta \ln Q^D_{HST,t-1}$	0.60	0.55	1.04**	0.02
	(0.65)	(0.64)	(0.47)	(0.44)
$\Delta \ln GINI_t$	-2.43	-3.47	-2.34	-2.21
	(2.79)	(2.76)	(2.00)	(1.88)
$\Delta \ln HOUST_t$	0.19	0.50*	0.40**	0.46**
	(0.25)	(0.25)	(0.18)	(0.17)
$\Delta \ln RGDPCAP_t$	-1.18	0.09	0.54	0.09
	2.73)	(2.69)	(1.96)	(1.83)
t	-0.00	-0.00	0.00	0.00
	(<0.01)	(<0.01)	(<0.01)	(<0.01)
Obs.	31	31	31	31
R^2	0.10	0.30	0.43	0.35
R^2_a	-0.23	0.03	0.21	0.10
Wald	F*(8,21)= 0.96	F*(8,21)= 1.10	F*(8,21)= 1.96	F*(8,21)= 1.40

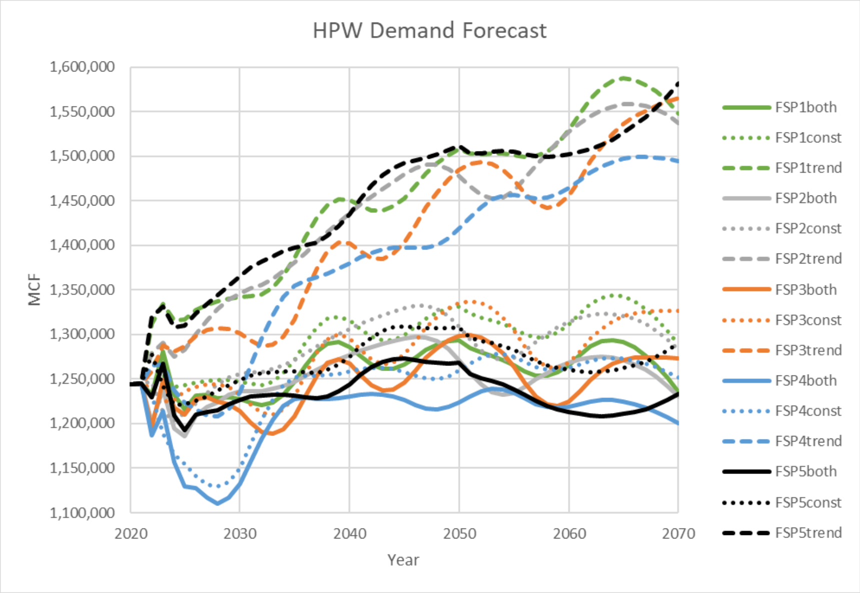
$*p<0.1$, $**p<0.05$, $***p<0.01$

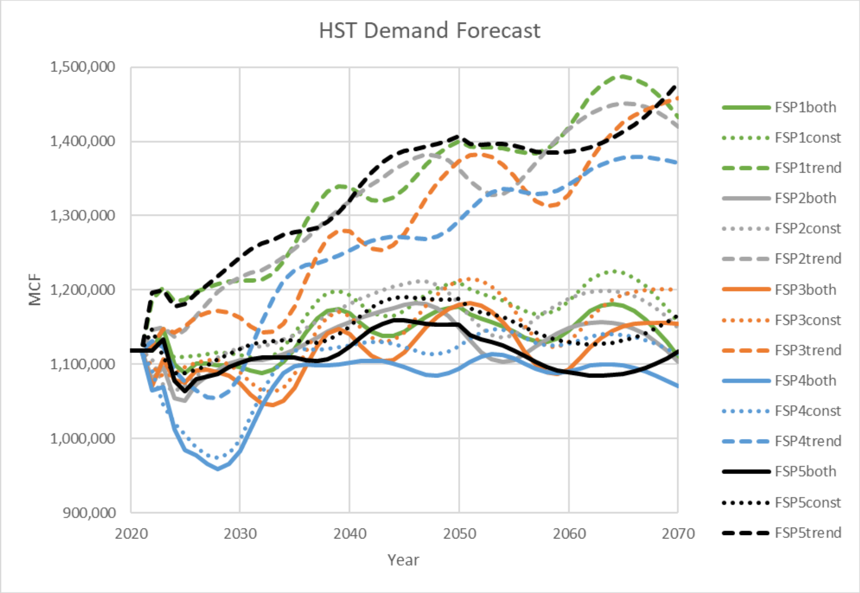
Demand Forecasts by Product Type (.PRJ) (Softwood)





Demand Forecasts by Product Type (.PRJ) (Hardwood)





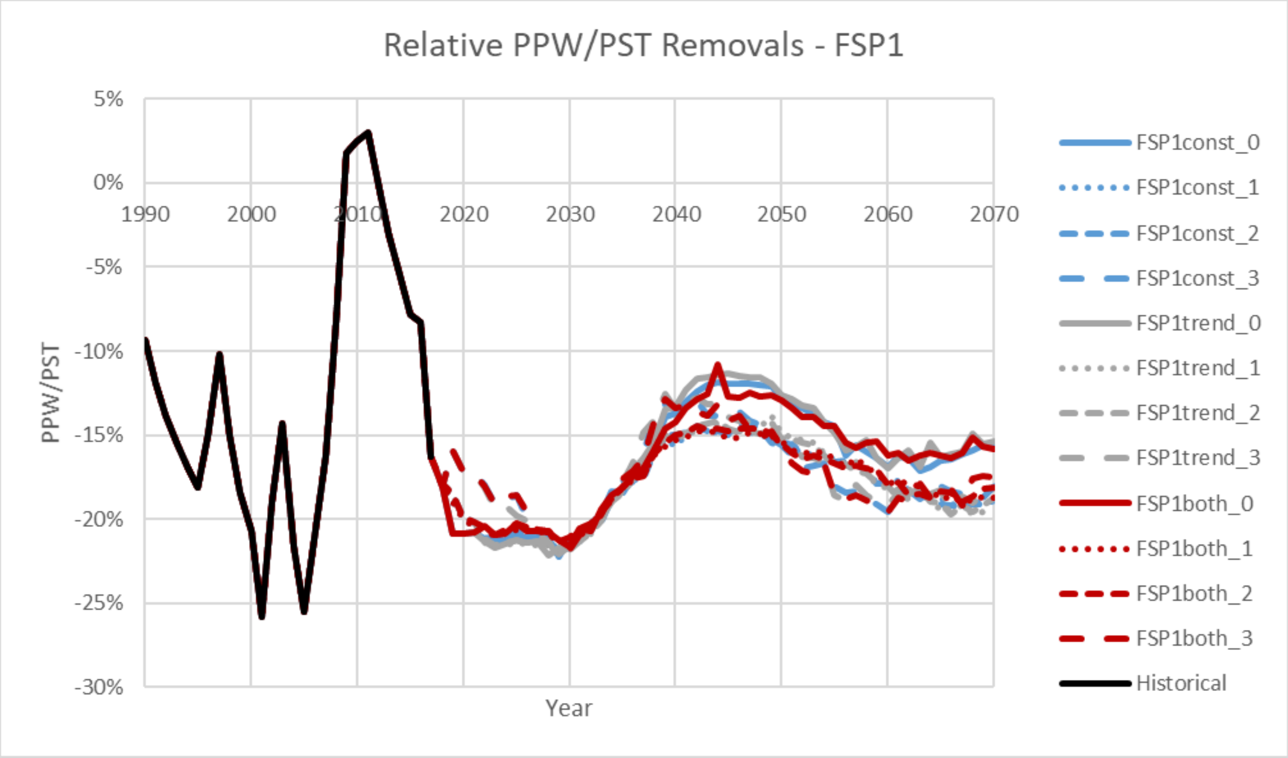
Forest Sector Pathways (FSPs) – SRTS parameterization

- FSP1 (“Sustainability”): SSP1 roundwood demand forecast + SSP1 L.U.C. coefficients
  - No carbon fertilization (PMAP Growth OFF)
  - PST Resid to PPW: 35%
  - Cull Factors: 25% (PST), 25% (HST)
- FSP2 (“Business-as-Usual”): SSP2 roundwood demand forecast + SSP2 L.U.C. coefficients
  - Carbon Fertilization (RCP 4.5)
  - PST Resid to PPW: 30%
  - Cull Factors: 25% (PST), 25% (HST)
- FSP3 (“Regional Rivalry”): SSP3 roundwood demand forecast + SSP3 L.U.C. coefficients
  - Carbon Fertilization (RCP 4.5)
  - PST Resid to PPW: 25%
  - Cull Factors: 20% (PST), 20% (HST)
- FSP4 (“Inequality”): SSP4 roundwood demand forecast + SSP4 L.U.C. coefficients
  - Carbon Fertilization (RCP 4.5)
  - PST Resid to PPW: 30%
  - Cull Factors: 20% (PST), 20% (HST)
- FSP5 (“Fossil-fueled Development”): SSP5 roundwood demand forecast + SSP5 L.U.C. coefficients
  - Carbon Fertilization (RCP 8.5)
  - PST Resid to PPW: 30%
  - Cull Factors: 25% (PST), 25% (HST)

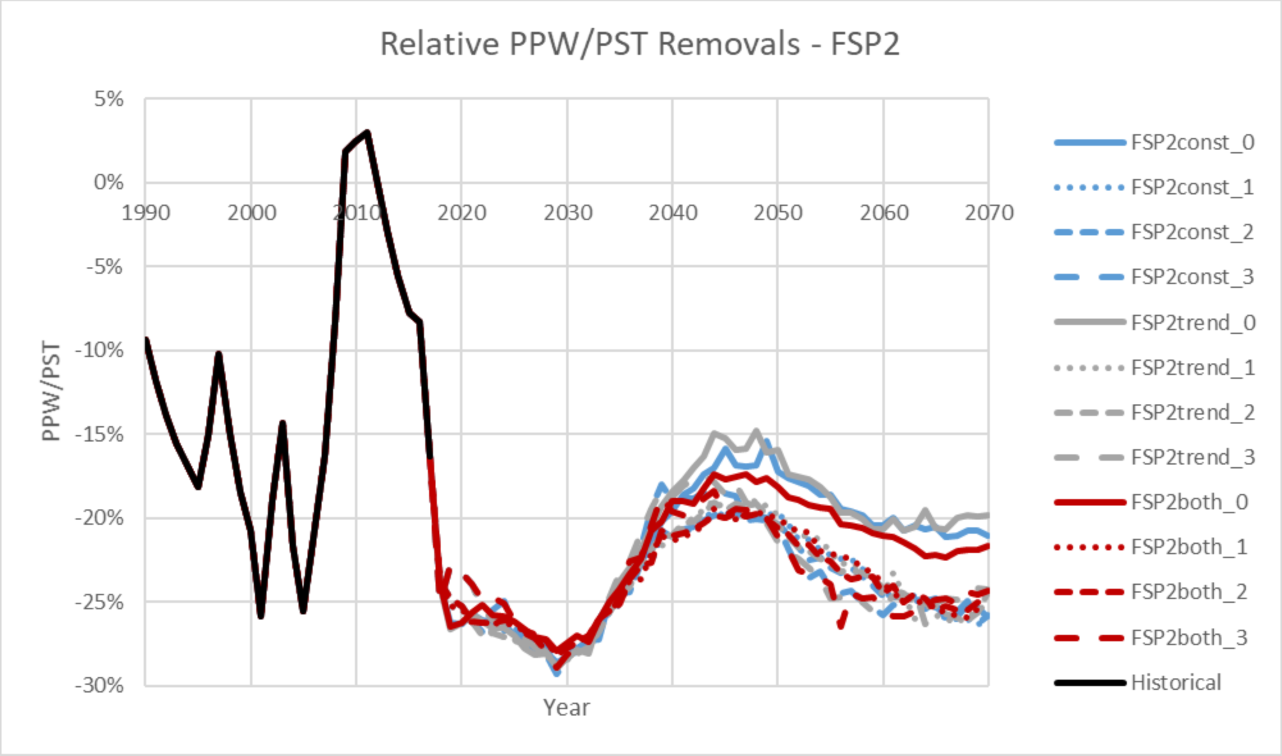
Representation of Deferred Harvest in SRTS (.PW file construction)

- No Offset MKT (Baseline): $W_{PPW} = 1{,}000; W_{PST} = 1{,}000$
- Low Offset MKT Activity: $W_{PPW} = 100; W_{PST} = 10{,}000$
- Medium Offset MKT Activity: $W_{PPW} = 10; W_{PST} = 100{,}000$
- High Offset MKT Activity: $W_{PPW} = 1; W_{PST} = 1{,}000{,}000$

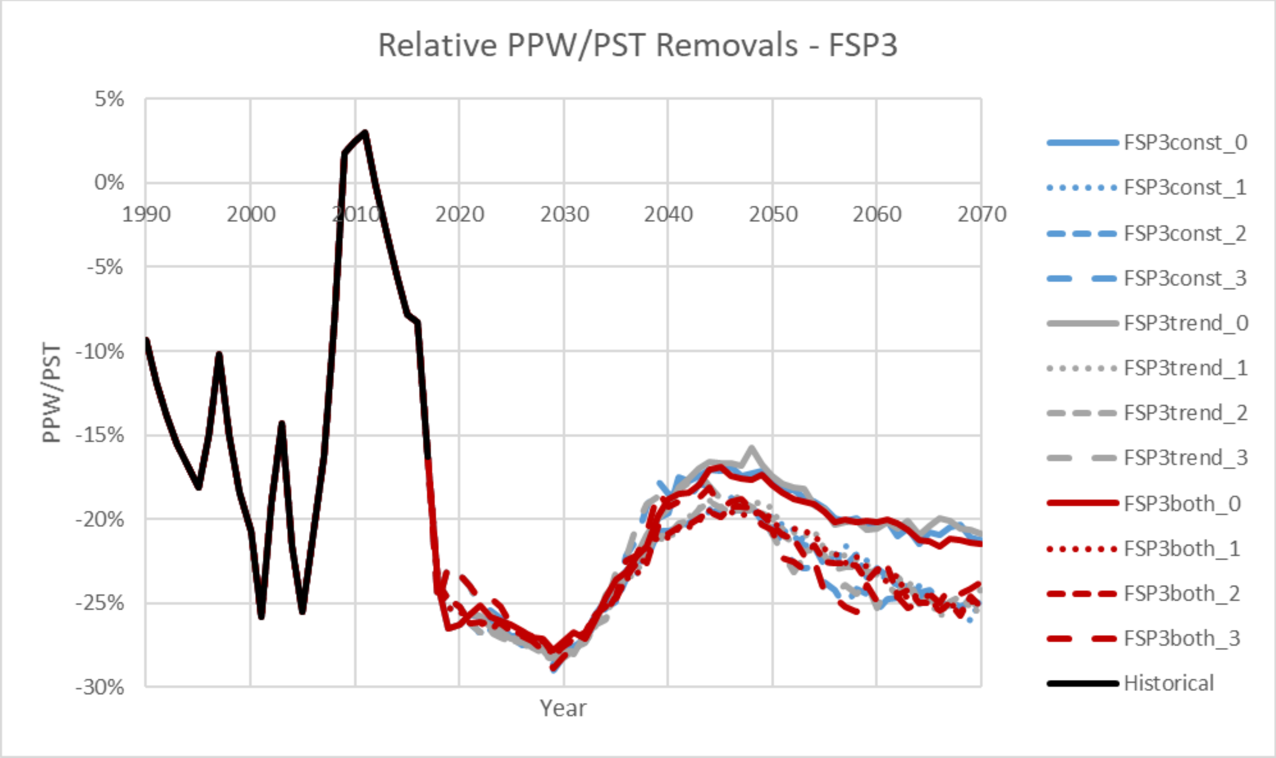
Results – Pulpwood Harvests (FSP1 – “Sustainability”)



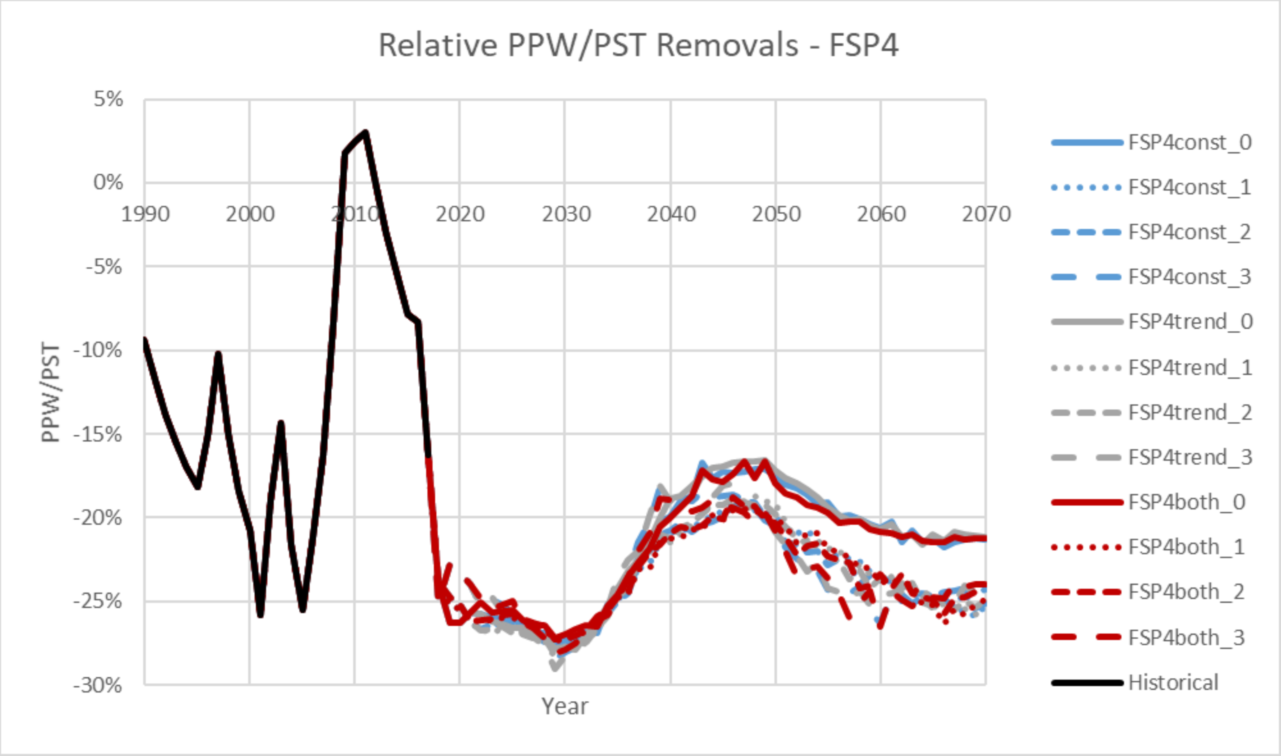
Results – Pulpwood Harvests (FSP2 – "Business-as-Usual")



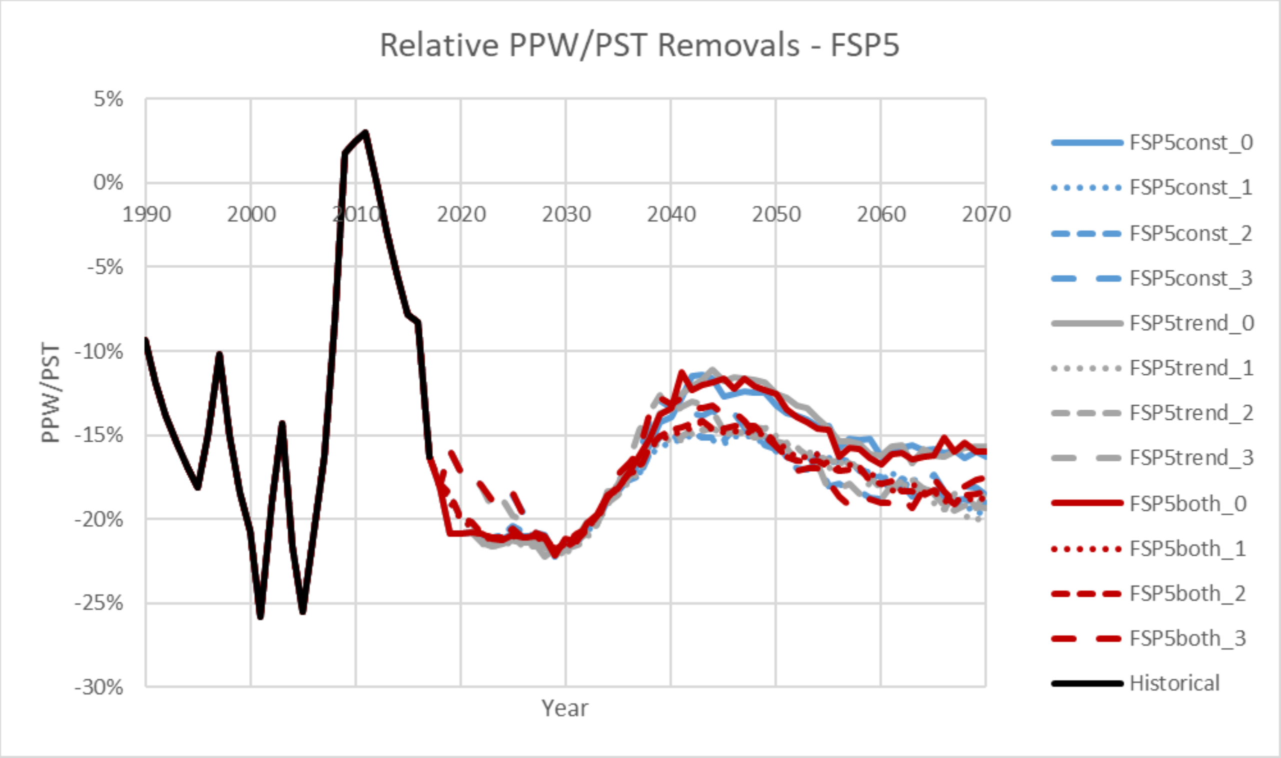
Results – Pulpwood Harvests (FSP3 – "Regional Rivalry")

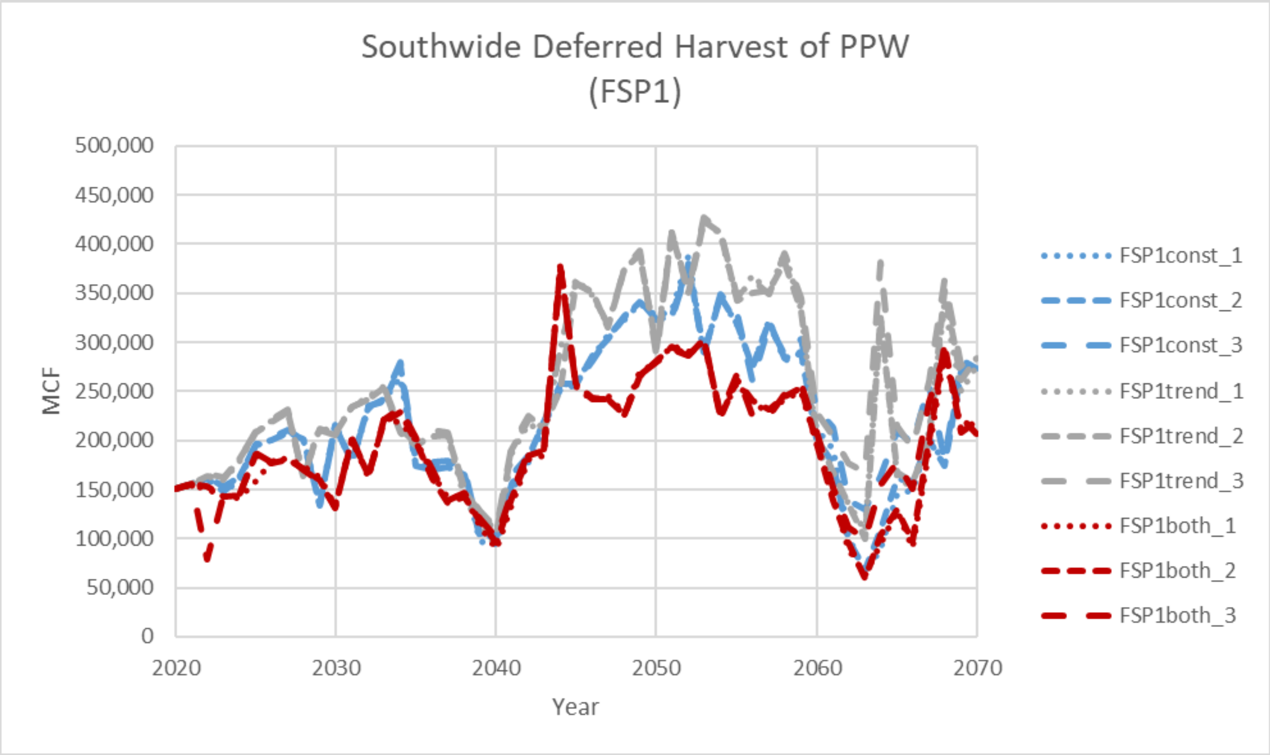


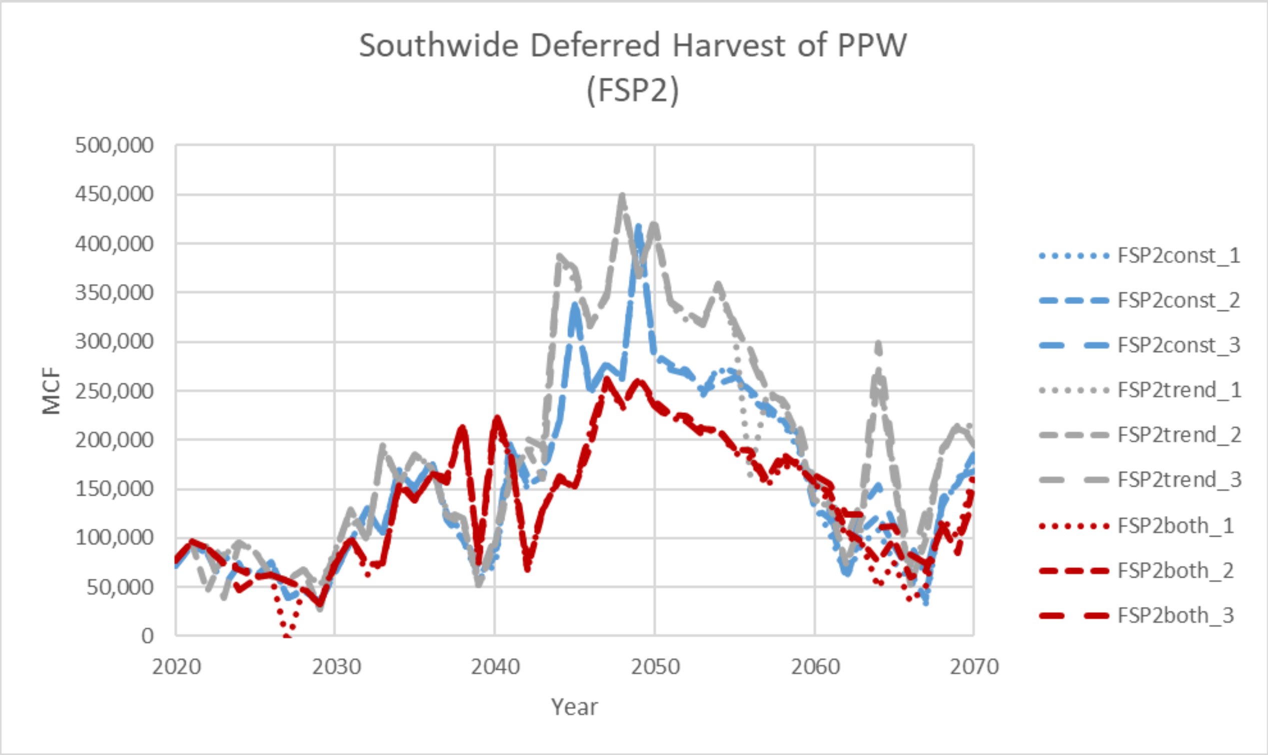
Results – Pulpwood Harvests (FSP4 – “Inequality”)

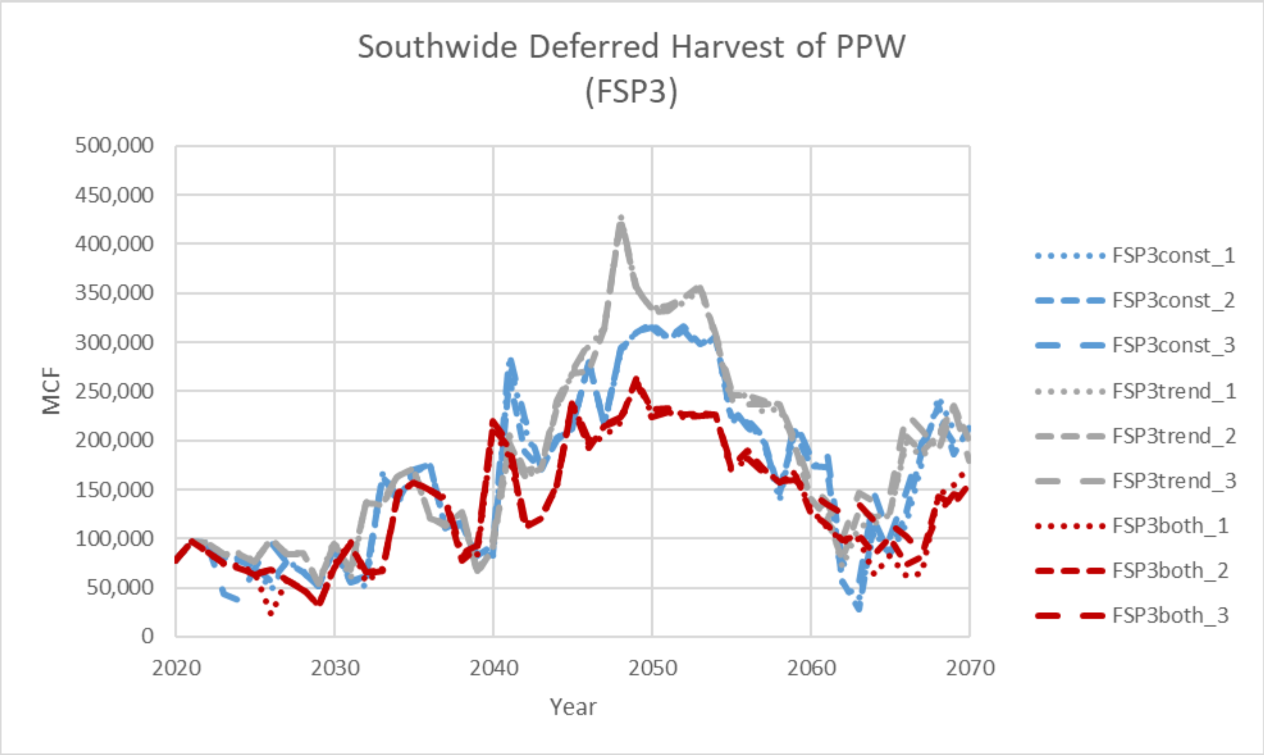


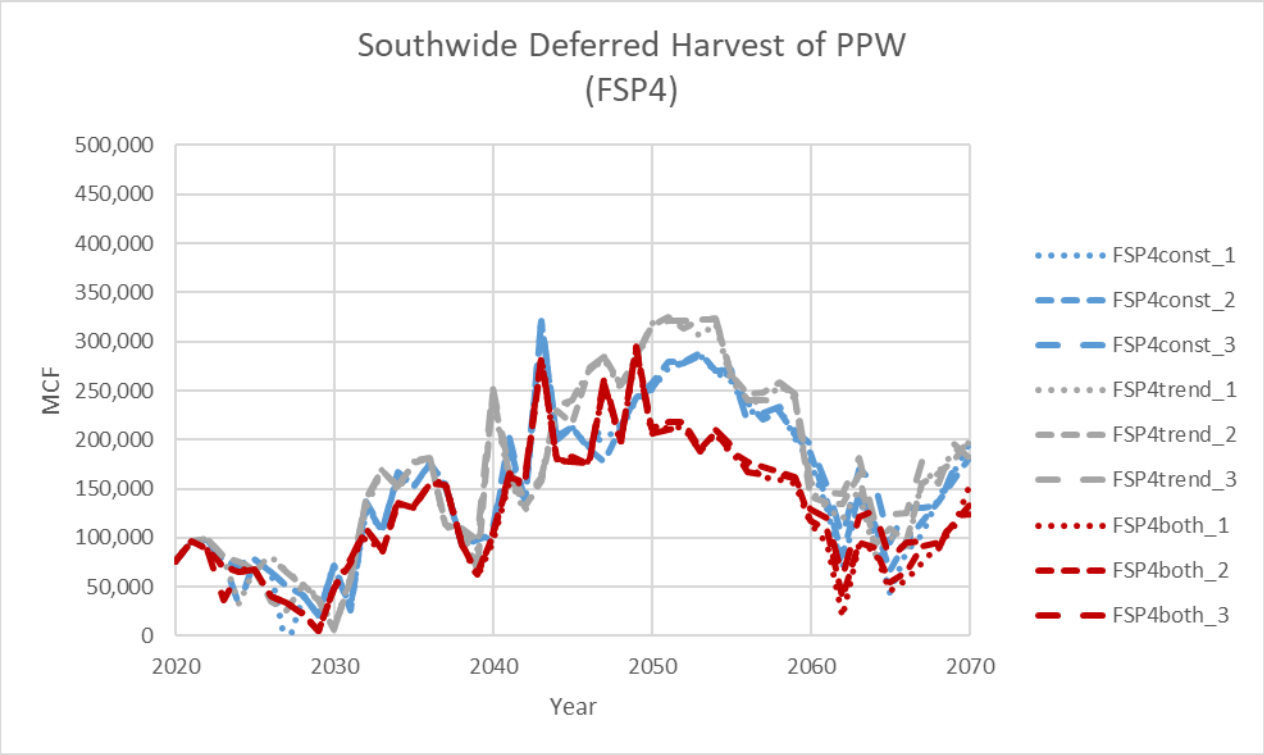
Results – Pulpwood Harvests (FSP5 – “Fossil-fueled Development”)

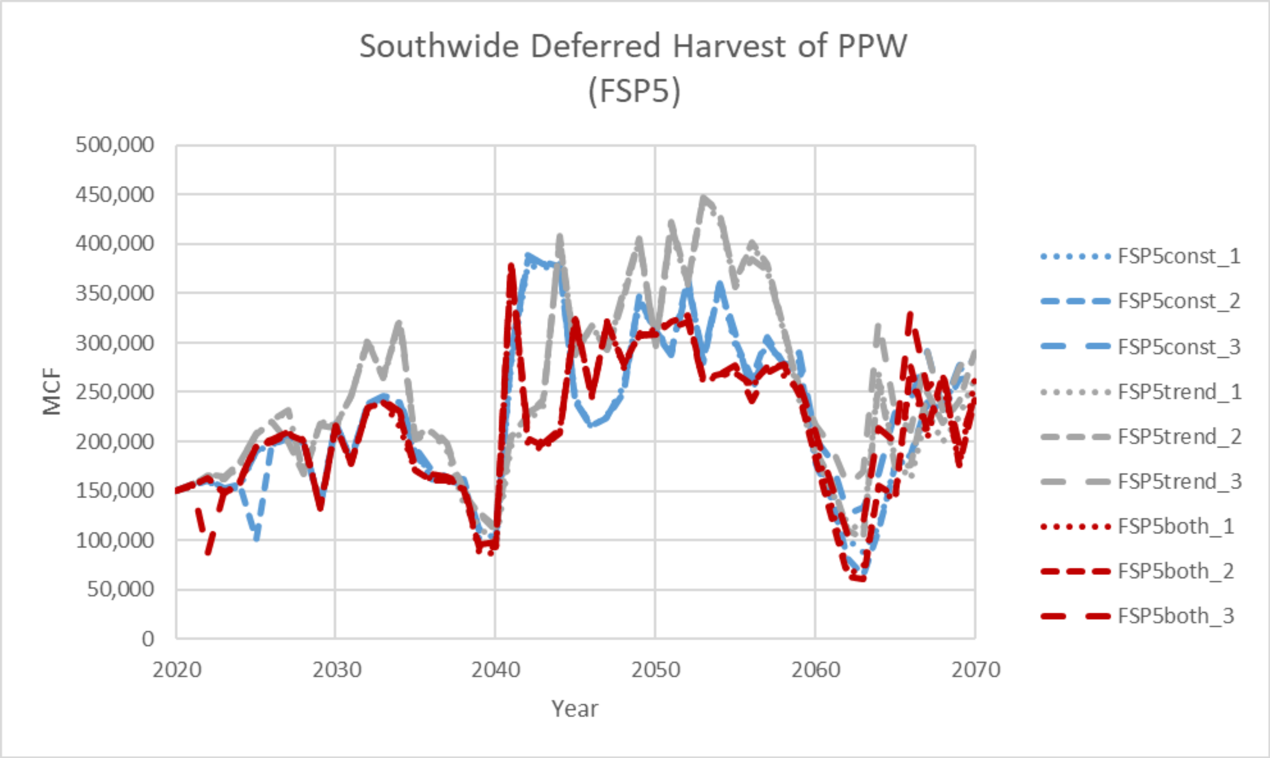



Southwide Deferred Harvest of PPW
(FSP1)
500,000
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
MCF
2020
2030
2040
2050
2060
2070
Year
FSP1const_1
FSP1const_2
FSP1const_3
FSP1trend_1
FSP1trend_2
FSP1trend_3
FSP1both_1
FSP1both_2
FSP1both_3

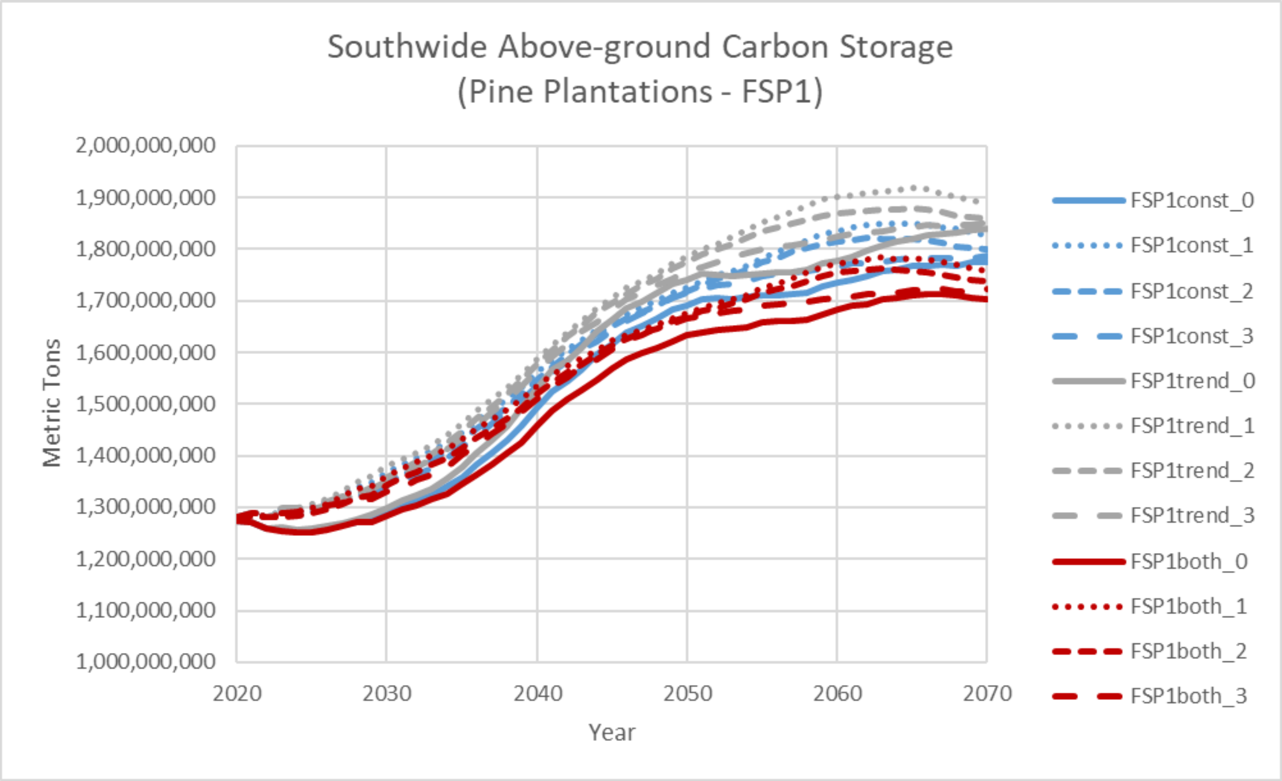

Southwide Deferred Harvest of PPW
(FSP2)
500,000
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
MCF
2020
2030
2040
2050
2060
2070
Year
FSP2const_1
FSP2const_2
FSP2const_3
FSP2trend_1
FSP2trend_2
FSP2trend_3
FSP2both_1
FSP2both_2
FSP2both_3


Southwide Deferred Harvest of PPW
(FSP3)
500,000
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
MCF
2020
2030
2040
2050
2060
2070
Year
FSP3const_1
FSP3const_2
FSP3const_3
FSP3trend_1
FSP3trend_2
FSP3trend_3
FSP3both_1
FSP3both_2
FSP3both_3

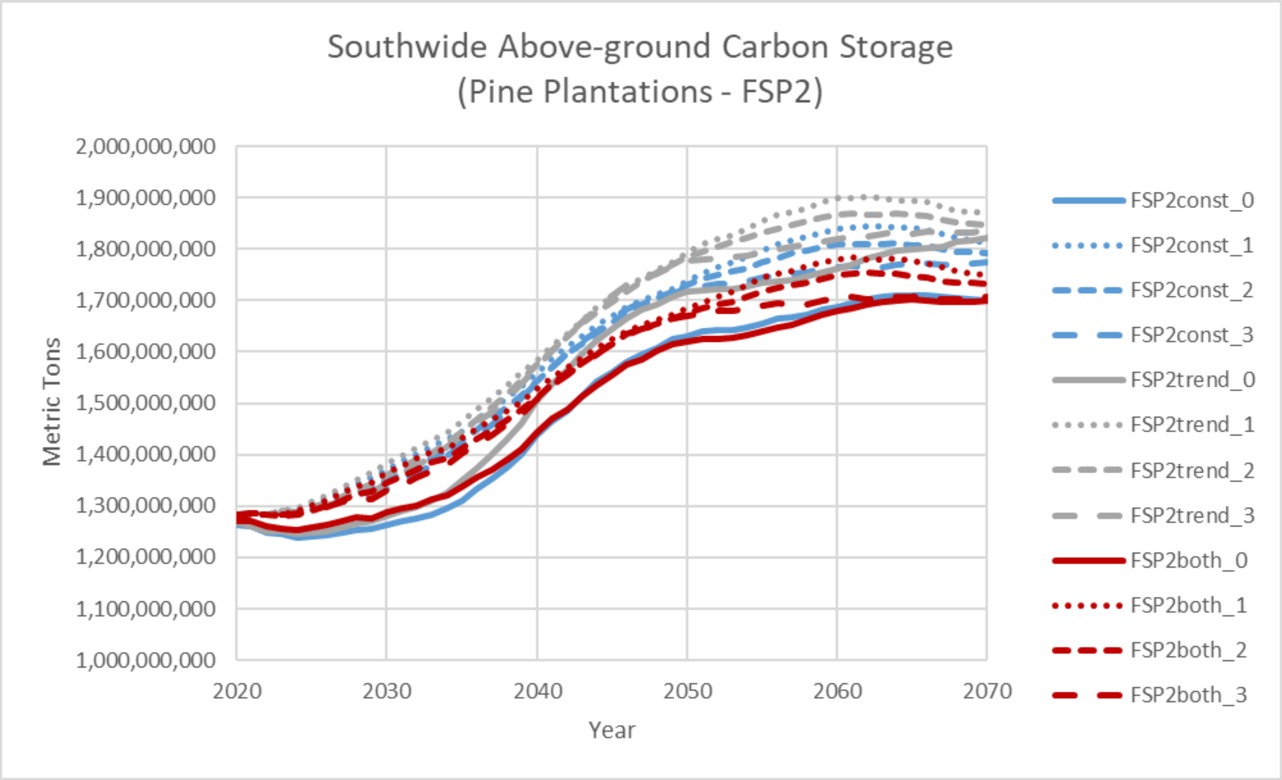

Southwide Deferred Harvest of PPW
(FSP4)
500,000
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
MCF
2020
2030
2040
2050
2060
2070
Year
FSP4const_1
FSP4const_2
FSP4const_3
FSP4trend_1
FSP4trend_2
FSP4trend_3
FSP4both_1
FSP4both_2
FSP4both_3


Southwide Deferred Harvest of PPW
(FSP5)
MCF
500,000
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
2020
2030
2040
2050
2060
2070
Year
FSP5const_1
FSP5const_2
FSP5const_3
FSP5trend_1
FSP5trend_2
FSP5trend_3
FSP5both_1
FSP5both_2
FSP5both_3

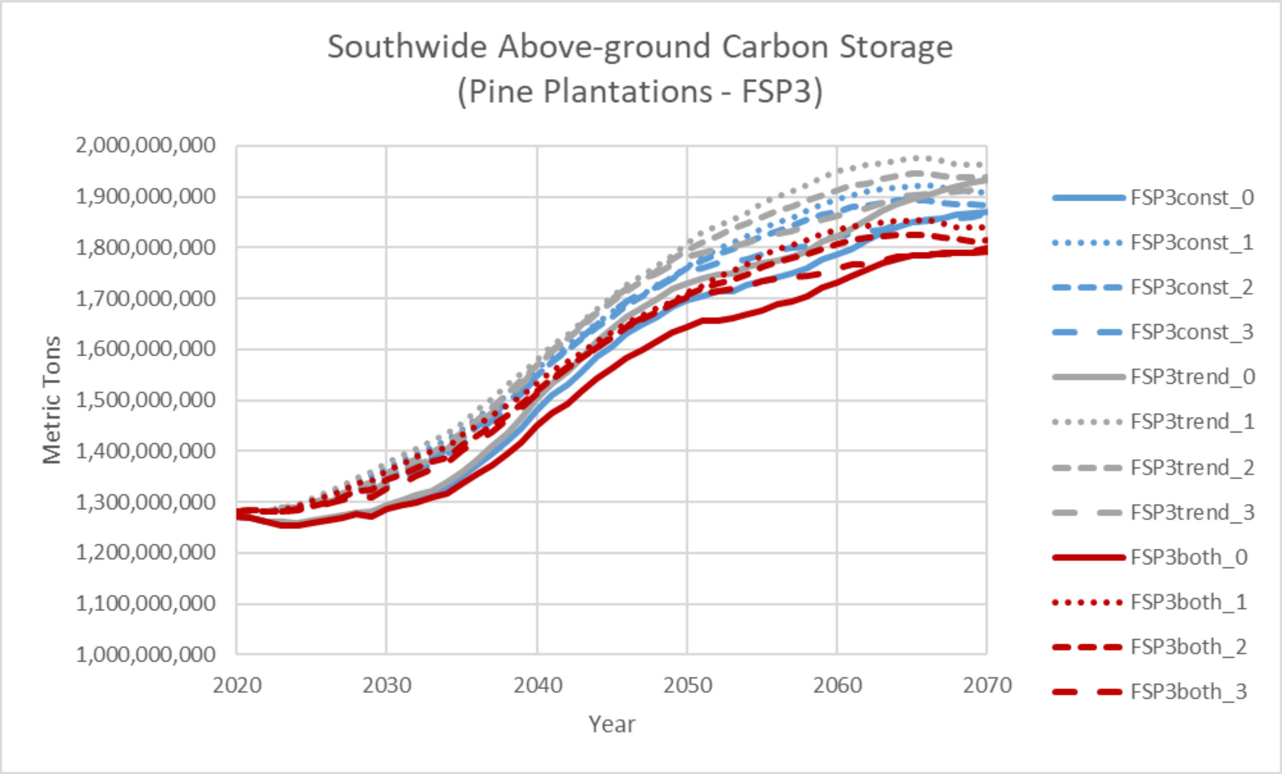
Results – Above-Ground Carbon Storage (FSP1)



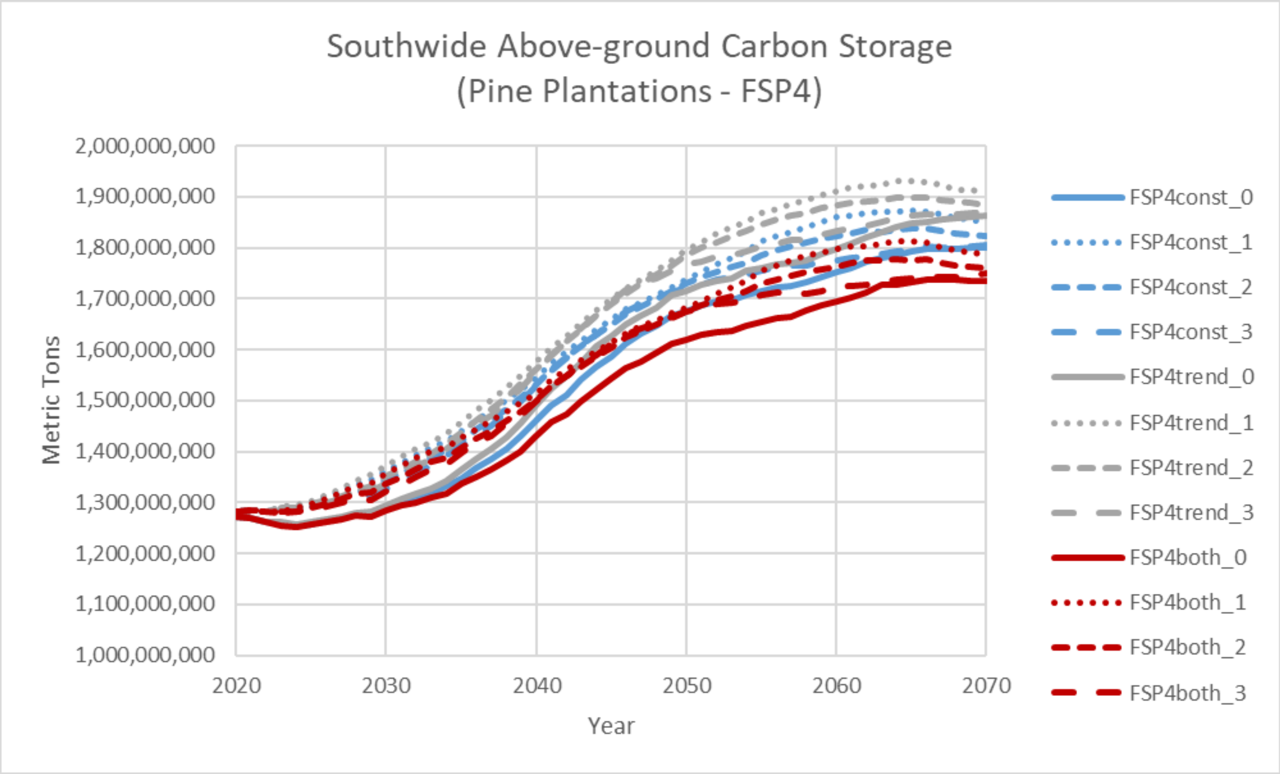
Results – Above-Ground Carbon Storage (FSP2)



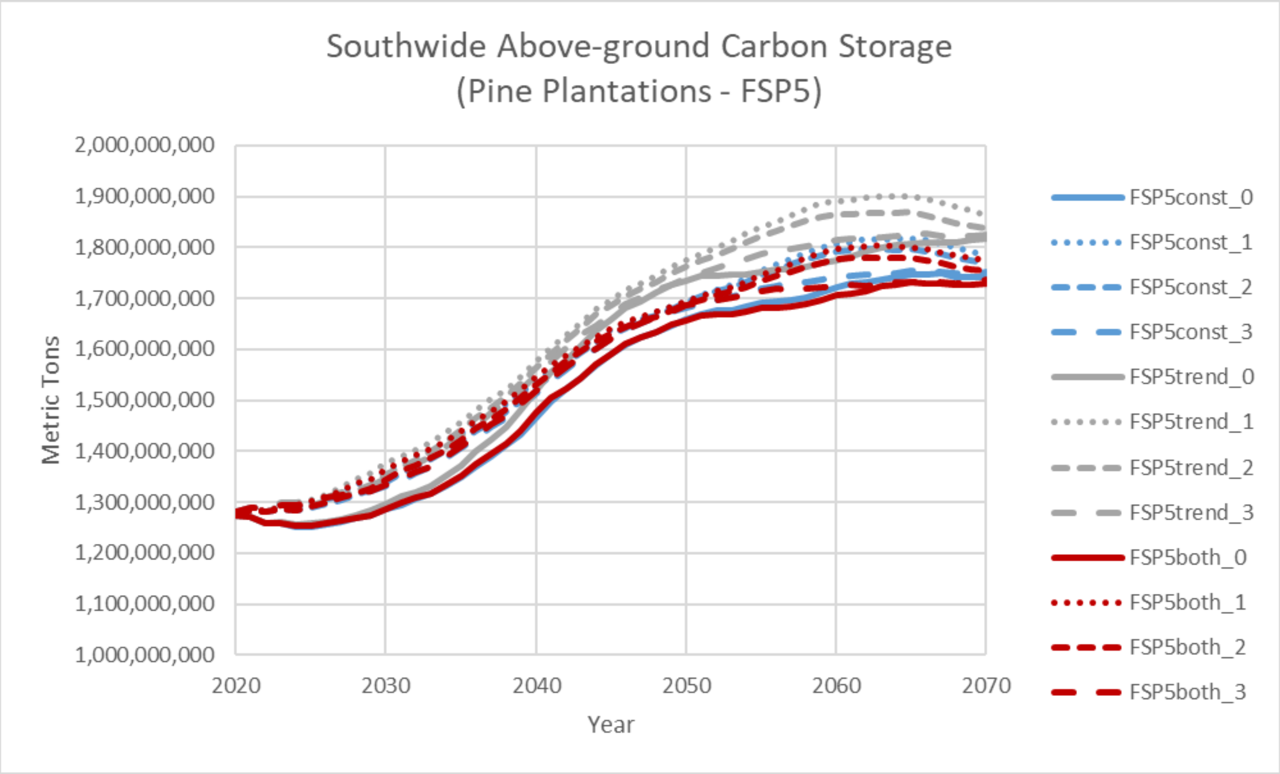
Results – Above-Ground Carbon Storage (FSP3)



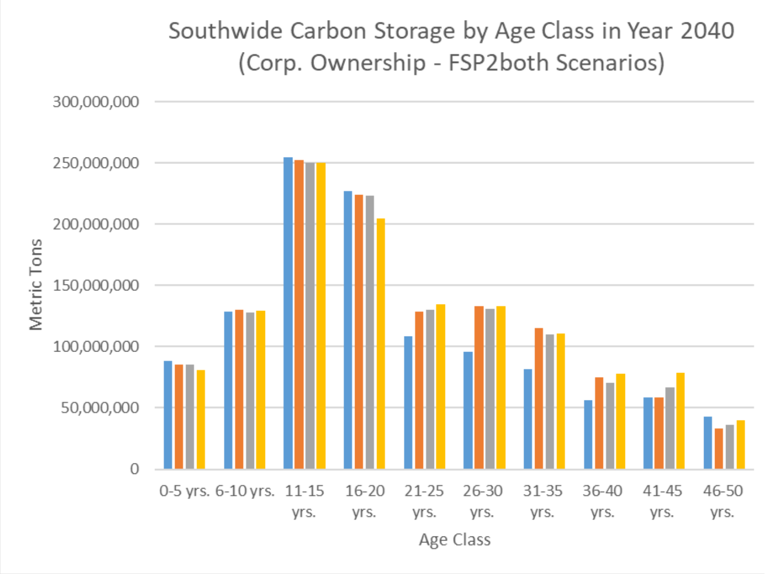
Results – Above-Ground Carbon Storage (FSP4)

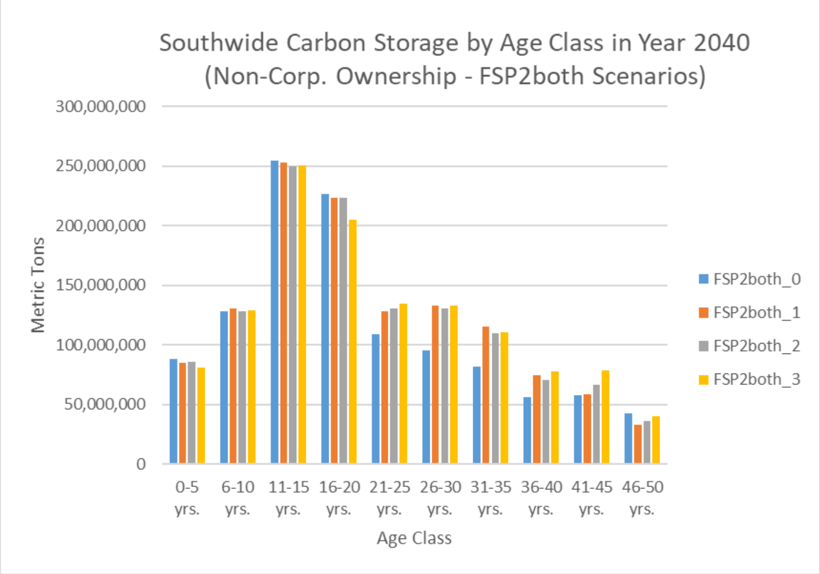


Results – Above-Ground Carbon Storage (FSP5)

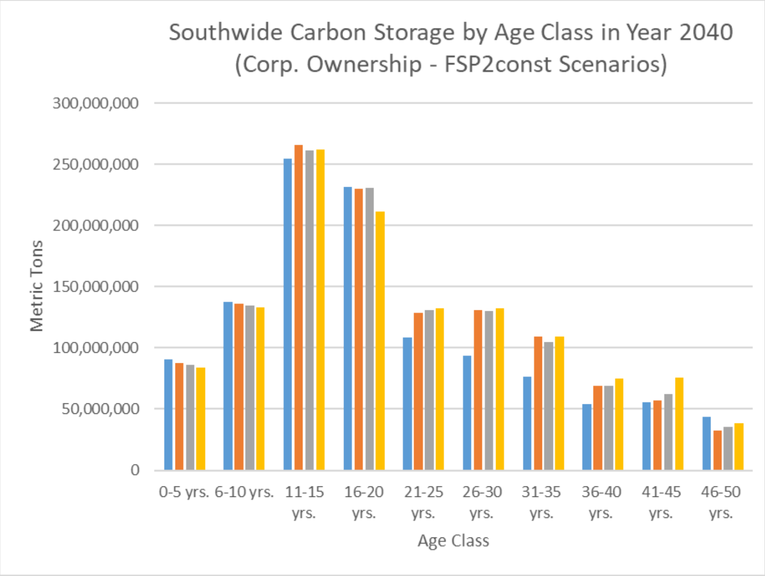


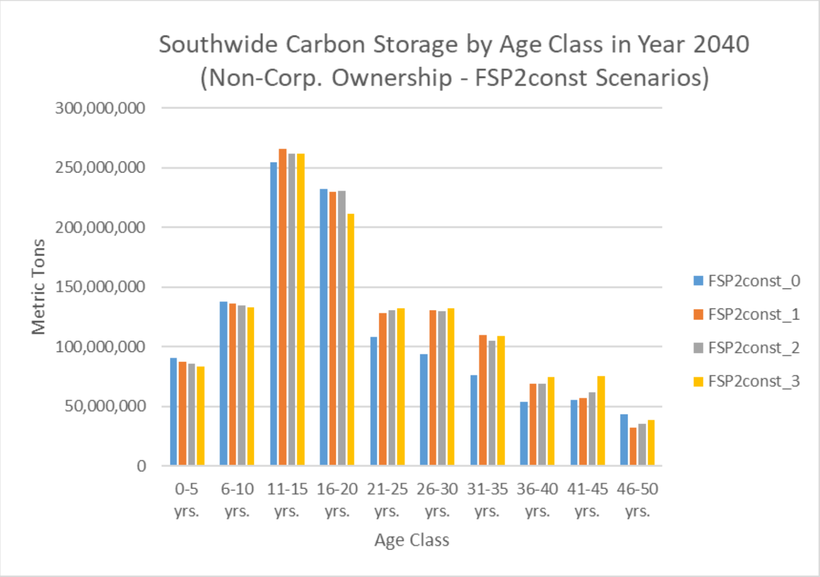
Results – Above-Ground Carbon Storage (FSP2trend – Falling/Low Demand)



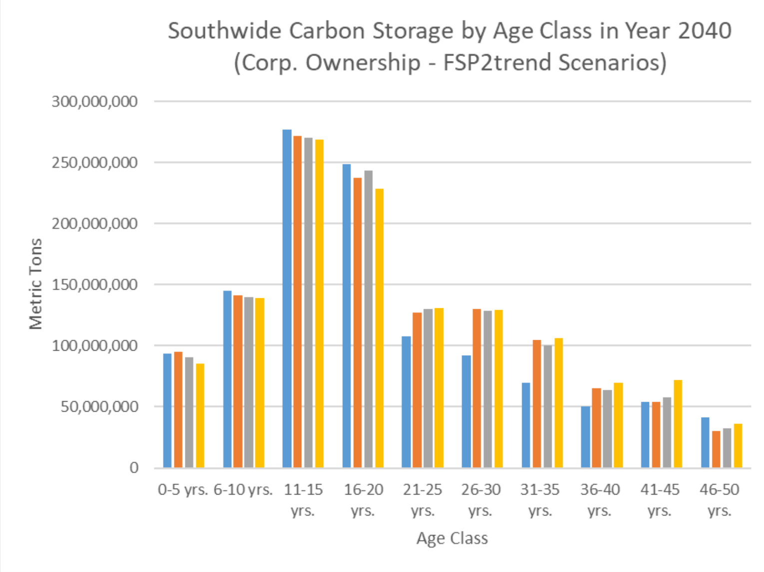


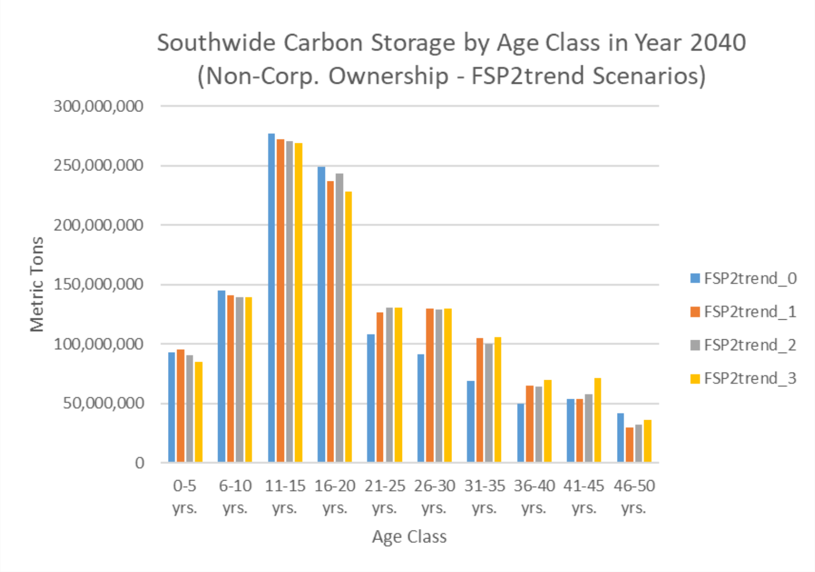
Results – Above-Ground Carbon Storage (FSP2trend – Constant/Flat Demand)





Results – Above-Ground Carbon Storage (FSP2trend – Rising/High Demand)





Offset Broker's Reaction Curve

- Multiple Linear Regression model w/ SRTS output data from 60 scenarios (annual, region-level data for each projection).

$$C = f(P_P, P_H, DEF_{PPW}, YR, RG, OW, PCTCULL, PSTRESID, PMAP, RGDPCAP, HOUST, GINI) + \varepsilon$$

```
MODEL INFO:
Observations: 349044 (19836 missing obs. deleted)
Dependent Variable: C
Type: OLS linear regression

MODEL FIT:
F(188,348855) = 4952.27, p = 0.00
R² = 0.73
Adj. R² = 0.73
```

$$\frac{\partial \hat{C}}{\partial P_P} = \frac{\hat{\beta}_1 + \hat{\beta}_2(\ln P_H * YR) + \hat{\beta}_3(\ln P_H * YR^2) + \hat{\beta}_4 \ln DEF_{PPW} + \hat{\beta}_5 \ln P_H + \hat{\beta}_6\big(\ln P_H * YR * 1(RG = 4)\big) + \hat{\beta}_7\big(\ln P_H * YR^2 * 1(RG = 4)\big)}{P_P}$$

Offset Broker's Reaction Curve for AL-WCtrl Region (Year 2023, w/ Southwide PPW Harvest Deferrals of 125,000 MCF) (~5% of Annual Southwide PPW Removals)

- Assume the current price state is:
  - PPW - $10/ton
  - PST - $24/ton
  - HPW - $11/ton
  - HST - $33/ton
  - Expected southwide sequestration of ~11million tC02e

- Move from $10 to $9 would require an additional 333,456 Metric Tons of Above Ground Storage (or 1.22 million tCO2e)

Offset Broker's Reaction Curve for AL-WCtrl Region (Year 2023 – w/ Southwide PPW Harvest Deferrals of 250,000 MCF) (~10% of Annual Southwide PPW Removals)

- Assume the current price state is:
  - PPW - $10/ton
  - PST - $24/ton
  - HPW - $11/ton
  - HST - $33/ton
  - Expected southwide sequestration of ~11million tC02e

- Move from $10 to $9 would require an additional 475,938 Metric Tons of Above Ground Storage (or 1.74 million tCO2e)

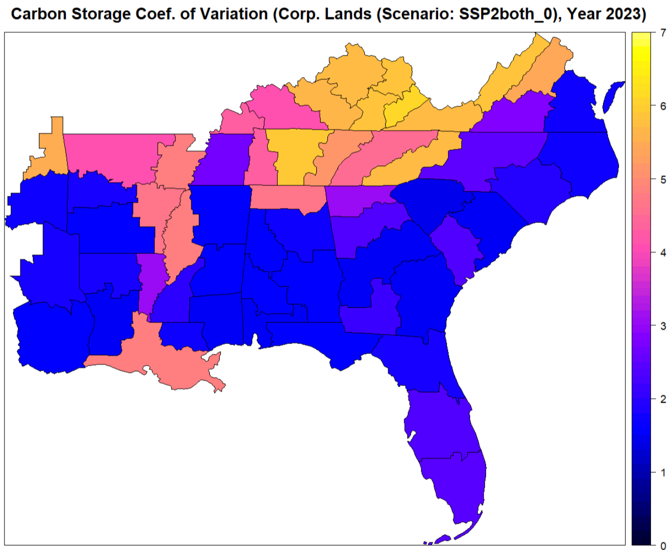
Offset Broker's Reaction Curve for AL-WCtrl Region (Year 2030 – w/ Southwide PPW Harvest Deferrals of 250,000 MCF) (~10% of Annual Southwide PPW Removals)

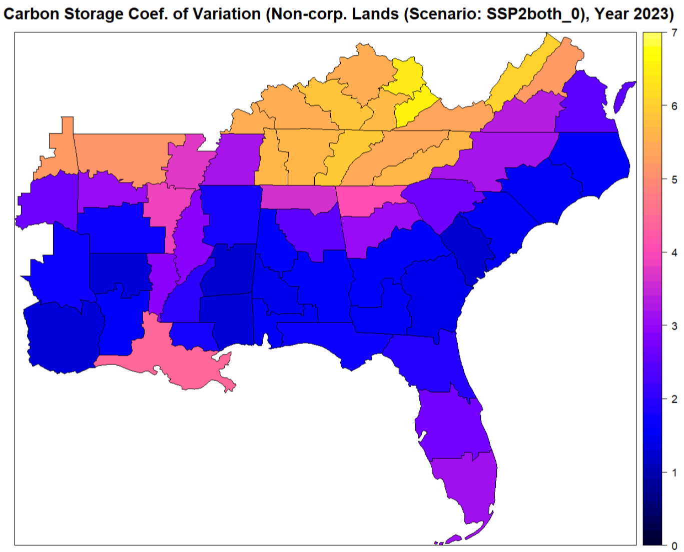
- Assume the current price state is:
  - PPW - $10/ton
  - PST - $24/ton
  - HPW - $11/ton
  - HST - $33/ton
  - Expected southwide sequestration of ~12.3million tC02e

- Move from $10 to $9 would require an additional 371,170 Metric Tons of Above Ground Storage (or 1.36 million tCO2e)

Quantifying Additionality via the Risk of Above-ground Carbon Loss (coefficient of variation)

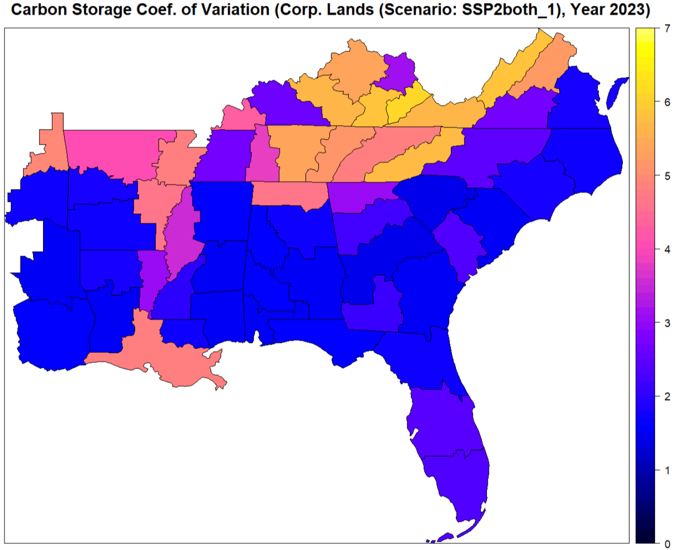
- St. Dev. of C stored across age classes in year 2023 divided by the average level of C storage across age classes in year 2023 (**FSP2both_0**).

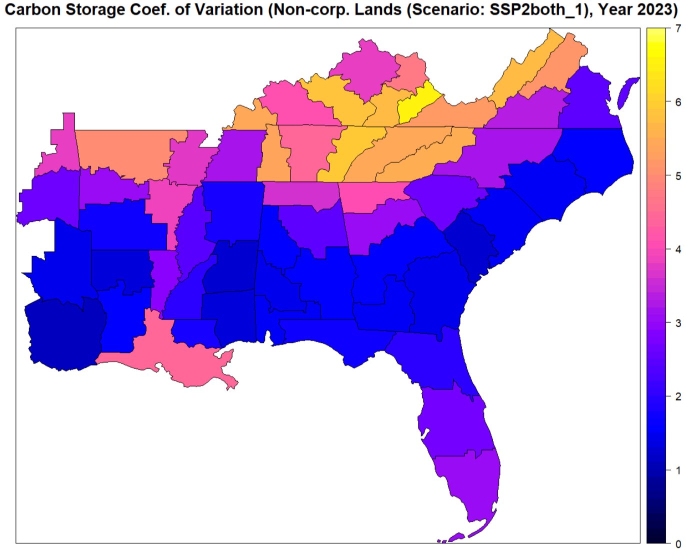




Quantifying Additionality via the Risk of Above-ground Carbon Loss (coefficient of variation)

- St. Dev. of C stored across age classes in year 2023 divided by the average level of C storage across age classes in year 2023 (**FSP2both_1**).





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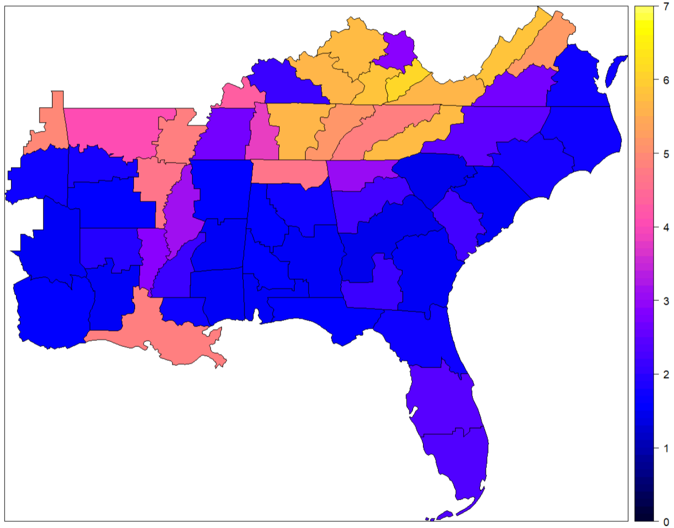
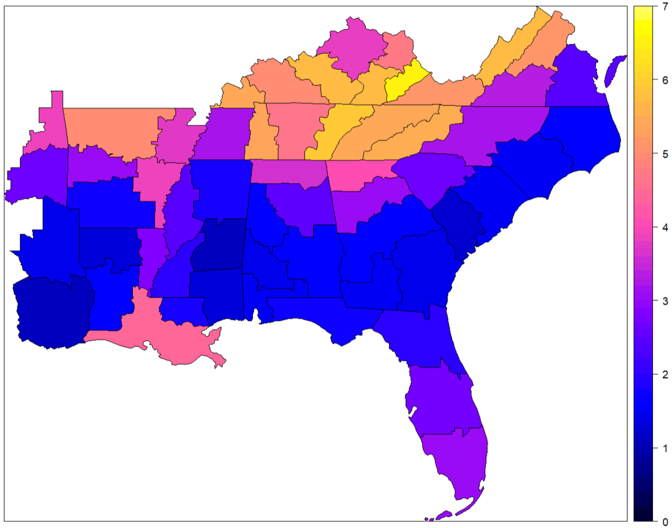
Quantifying Additionality via the Risk of Above-ground Carbon Loss (coefficient of variation)

- St. Dev. of C stored across age classes in year 2023 divided by the average level of C storage across age classes in year 2023 (**FSP2both_2**).

Carbon Storage Coef. of Variation (Corp. Lands (Scenario: SSP2both_2), Year 2023)

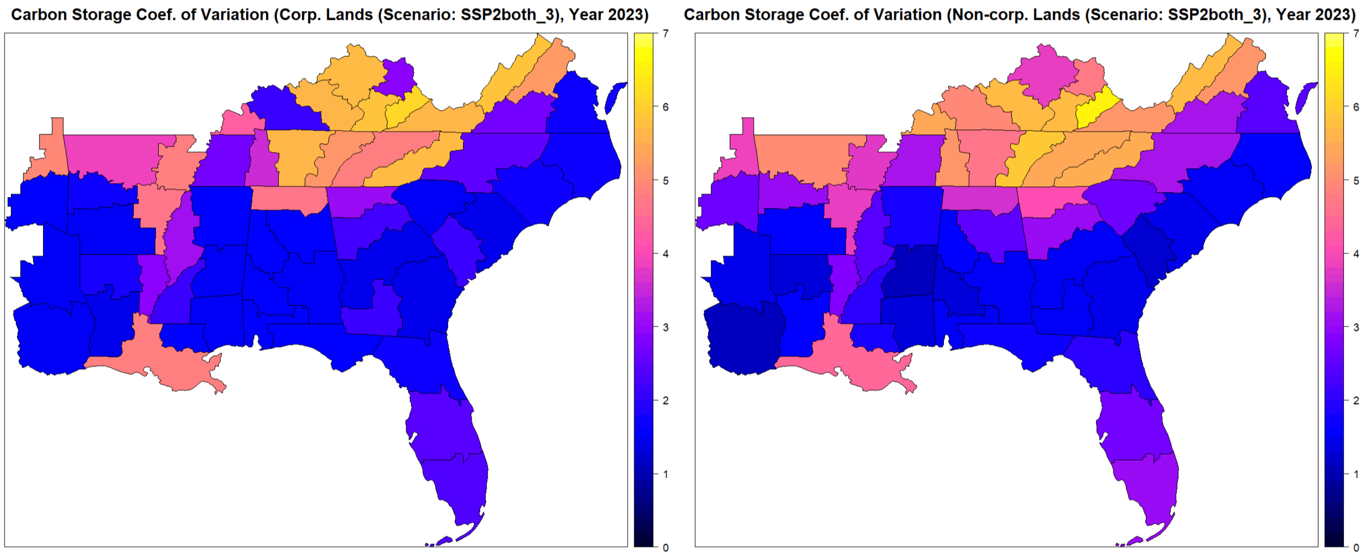


Carbon Storage Coef. of Variation (Non-corp. Lands (Scenario: SSP2both_2), Year 2023)



Quantifying Additionality via the Risk of Above-ground Carbon Loss (coefficient of variation)

- St. Dev. of C stored across age classes in year 2023 divided by the average level of C storage across age classes in year 2023 (**FSP2both_3**).



Next Steps

- More work is needed to understand how product weights relate to harvest deferrals in SRTS.
- Land rents informed by income from carbon sequestration.
- Refinement of regression equation used to estimate C storage.
- Forest growth uncertainty.
- Intra-regional Leakage and basin-level product weights.

References

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- Badgley, G., Freeman, J., Hamman, J. J., Haya, B., Trugman, A. T., Anderegg, W. R. L., & Cullenward, D. (2022). Systematic over-crediting in California's forest carbon offsets program. *Global Change Biology*, *28*(4), 1433–1445.
- Parisa, Z. "Latest NCX Forest Carbon Program Results Demonstrate Growth Across 39 US States" NCX Blog. 26 January, 2022.
- Parisa, Z., Pond, N. Vermeer, J. Jenkins. 2021. "Methodology for Improved Forest Management through targeted, short-term Harvest Deferral", Verified Carbon Standard. Document Prepared by NCX.
- Rossi, D., J. Baker, R. Abt. 2022. Quantifying additionality thresholds for forest carbon offsets in southern pine pulpwood markets. *Selected Paper prepared for presentation at the 2022 AAEA Meeting.* Anaheim, CA. July 31-Aug. 2.