



The Impacts of Changes in Federal Timber Harvest on Forest Carbon Sequestration in Western Oregon

IUFRO FOREST SECTOR MODELING CONFERENCE 2008

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Northwest Forest Plan and harvests on western Oregon federal forests

- Northwest Forest Plan
 - Federal forest management guidelines
 - Anticipated WOR cuts: 556 MMBF
 - Actual WOR harvests:
 - 315 MMBF ('95-'99)
 - 94 MMBF ('00-'07)
 - Plan rules constrain form and location of harvest

- Continued debate on federal forest management and timber harvest
 - Increase cuts to NWFP levels proposed for economic benefits and wildfire
 - Possible losses of ecosystem values



Carbon and Public Forests

- Possible carbon losses when old growth public forests cut (Harmon et al. 1990, Schulze et al. 2000)
- WOR, WWA federal timberlands sequestered 200Mt of carbon (1953-2000) (Smith & Heath, 2004)
- Future public carbon storage?
 - Depends on harvests and growth
 - Harvest variation limited by NWFP



<http://www.krisweb.com/krisgualala/krisdb/html/krisweb/index.htm>

Federal Land-Use Allocations and Key Watersheds

	Northwest Forest Plan		
	Key Watersheds		
LAND USE ALLOCATION	Tier 1+2	non-Key	
	<i>Thousand acres</i>		
Wilderness and Reserves	657	767	
Late Successional Reserves	1,318	1,756	} 4,612
Adaptive Management Areas	76	497	
Matrix and Riparian Reserves	684	2,359	
Totals	2,735	5,379	8,114

Note: Areas include forested and non-forested lands



Questions

- **What would be the impacts on regional carbon flux of variation in allowable levels of harvest on federal forest lands?**
 - Substitution across owners
 - Changes in industry composition
- **Would it be possible to achieve a given level of regional net forest carbon flux with a smaller reduction in regional timber harvest through “coordinated” management of the joint public-private land base?**
 - Age and stocking structures of federal and private lands differ markedly with a wide range of current stocking and growth in each ownership



OVERVIEW OF MODELING APPROACH

DYNAMIC REGIONAL FOREST SECTOR MODEL
(MAXIMIZE DISCOUNTED LOG MARKET SURPLUS)

LOG DEMAND: LUMBER and PLYWOOD MILLS
PROCESSING CAPACITY ENDOGENOUS (OUTPUT BOUND AND
DEMAND SHIFT)

LOG SUPPLY: PRIVATE and PUBLIC FOREST LANDS
INVENTORY and SILVICULTURAL REGIME ENDOGENOUS

CARBON ACCOUNTING IN SIX POOLS: TREES (LIVE AND DEAD), UNDERSTORY,
FOREST FLOOR (LITTER), WOODY
DEBRIS (LARGE), SOIL AND PRODUCTS

TIMBERLAND AREA CHANGE EXOGENOUS

REGIONAL BOUNDARIES: SUPPLY OF LOG IMPORTS TO REGION
DEMAND FOR LOG EXPORTS FROM REGION

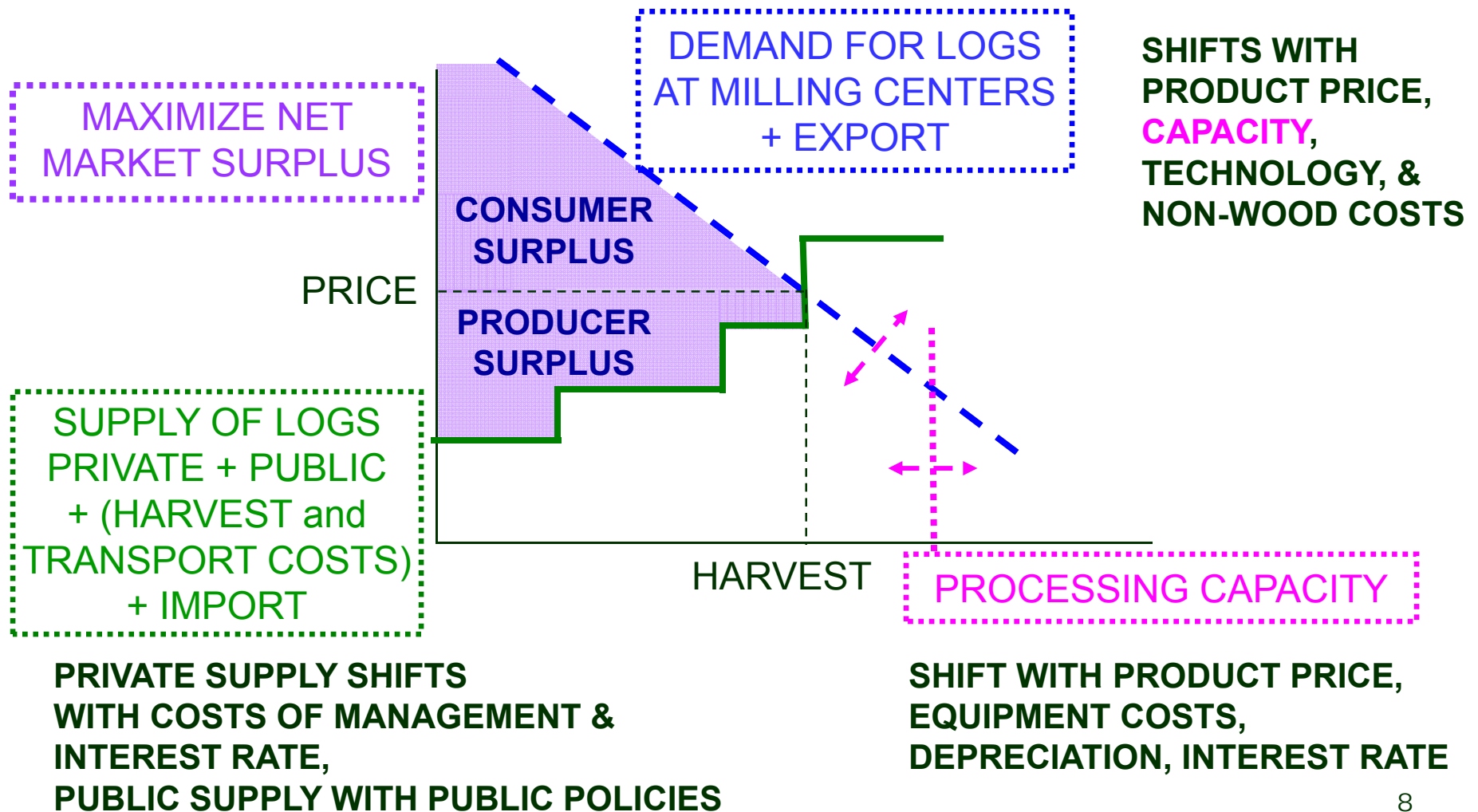


SCENARIOS

- ALTERNATIVE LEVELS OF REGIONAL FEDERAL HARVEST (0 to MAX S-Y NDEF)
 - VOLUMES OFFERED FOR SALE (UPPER BOUND), NOT A FIXED LEVEL

- REGIONAL CARBON FLUX “TARGETS”
 - VARY HARVESTS BY ALL OWNERS TO MEET FLUX TARGET TO MINIMIZE MARKET WELFARE LOSSES

Methods: Spatial Market Model





Overall Model Structure

Maximize discounted sum of producers' and consumers' surplus less costs of transport, harvest, silviculture and investment, subject to constraints describing dynamics of inventory and mills.

OBJECTIVE FUNCTION

MAX $\sum_{\text{TIME}} [\sum_{\text{MILLS}} \text{Willingness to pay}(\text{Receipts}_{\text{MILLS}}, \text{Capacity}^{(i-1)}_{\text{EOR}})$

- **Capacity costs (Depreciation, Expansion)**
- **Transport costs (PLOTS → MILLS)**
- **Harvest costs**
- **Plant and silvicultural costs (public and private)] $(1 + r)^{-\text{TIME}}$**
- + **Discounted Terminal Private Inventory Contribution**



Overall Model Structure: Constraints

- (2) ALL “PLOTS” MUST BE ALLOCATED TO SOME REGIME IN EACH PERIOD
- (3) EVEN-AGED PLANTING \leq AREA HARVESTED IN NEW AND EXISTING EVEN-AGED STANDS EACH PERIOD
- (4) HARVEST DEFINITION
- (5) HARVEST AT LEAST AS LARGE AS LOG SHIPMENTS TO MILLS + EXPORTS
- (6) RECEIPTS AT MILLS NO LARGER THAN REGIONAL SHIPMENTS + IMPORTS
- (7) RECEIPTS AT MILLS NO LARGER THAN CAPACITY (NO MILL INVENTORY)
- (8) $CAPACITY_{MILLS} = CAPACITY_{MILLS, TIME-1}(1-\Delta)^5 + MAINTENANCE_{MILLS} + EXPANSION_{MILLS}$
- (9) CONVEXITY CONSTRAINTS (PIECE-WISE LINEARIZATION OF AREA UNDER DEMAND FUNCTIONS)
- (10) NON-NEGATIVITY



Nonlinearities and Solution

- Piece-wise linear approximation of quadratic willingness-to-pay integral under demand functions
- Capacity in receipts definition and in demand functions also endogenous
 - Iterative solution, using last iteration's capacity as input to current iteration
 - Cycle until solutions between iterations vary by less than $|\varepsilon|$



Log Demand

- Demand equations (lumber and plywood)
 - Estimate at regional level, disaggregate to mills
 - Normalized, restricted quadratic profit function approach

LOG DEMAND = D[LOG PRICE, PRODUCT PRICE (INCLUDING CHIPS), LABOR PRICE, TIME, CAPACITY]

- Log demand elasticities at sample means: -.47 for lumber, -.72 for plywood
- Disaggregate to mills in proportion to estimated mill outputs in 1998 (base year)
- Capacity
 - Capacity bounds product output (log consumption) at the mill level and regional capacity shifts the log demand relations
 - Capacity changes with depreciation (set at a constant rate) and additions (which follow a two-tier cost structure)
 - depreciation offset, only maintain current capacity
 - expansion (most costly)

$$\text{Capacity}(t) = \text{Capacity}(t-1)[1-\delta]^5 + \text{Depreciation Offset}(t) + \text{Expansion}(t)$$



LOG SUPPLY

■ PUBLIC LANDS

- UPPER BOUND ON HARVEST SET BY POLICY (ACTUAL HARVEST DEPENDS ON MARKET)
- SILVICULTURAL REGIMES MAY CHANGE AT TIME OF REGENERATION HARVEST WITHIN LIMITS OF NW FOREST PLAN LAND ALLOCATIONS
- CHOICE OF PARCELS TO OFFER BASED ON MINIMIZATION OF MANAGEMENT COSTS

■ PRIVATE LANDS

- ACT AS LAND VALUE MAXIMIZERS (GIVEN PRICES)
- ENDOGENOUS SELECTION OF FUTURE SILVICULTURAL REGIME AT TIME OF REGENERATION
- SAME REGIMES AND SAME INTEREST RATE USED FOR BOTH INDUSTRIAL AND NON-INDUSTRIAL OWNERS
- NON-INDUSTRIAL HARVEST SUBJECT TO CONSTRAINTS ON AGE CLASS STRUCTURE TO MIMIC IMPACTS OF NON-MARKET OBJECTIVES



INVENTORY AND YIELDS

- **INVENTORY MODELED AT THE PLOT LEVEL**
 - **PLOTS TREATED AS DISTINCT TIMBER LOCATIONS FOR TRANSPORT COSTS**
 - **PLOT CHARACTERISTICS ALLOW MORE DETAILED HARVEST COST COMPUTATIONS**
- **YIELDS FOR ALL SILVICULTURAL REGIMES ON EACH PLOT PROJECTED USING INDIVIDUAL TREE GROWTH MODELS**



CARBON ACCOUNTING

- **TREES (EQUATIONS FOR ABOVE AND BELOW-GROUND BIOMASS—TREE-BY-TREE)**
- **UNDERSTORY AND LITTER BASED ON YIELD-LIKE RELATIONS DEPENDING ON AGE SINCE LAST HARVEST**
- **LARGE WOOD DEBRIS BASED ON DECAYING INPUT FROM LAST HARVEST + DOWNED MORTALITY**
- **SOIL CONSTANT**
- **PRODUCTS BASED ON HALF-LIFE ANALYSIS**
- **CARBON COMPUTED VIA CONSTRAINTS IN SOLUTION (SO AVAILABLE TO POLICY SCENARIOS)**



PLAN OF SCENARIOS

- VARY MAXIMUM PUBLIC CUT FROM 0 TO MAX LRSY (NDEF)—OBSERVE REGIONAL FLUX IMPACTS
- FOR EACH PUBLIC HARVEST LEVEL, IMPOSE A REGIONAL CARBON FLUX TARGET THAT MAY VARY FROM CURRENT (2005) TO 2X CURRENT LEVELS—EXAMINE CHANGES IN HARVEST LEVELS AND COMPOSITION

Results: Current Carbon Stock

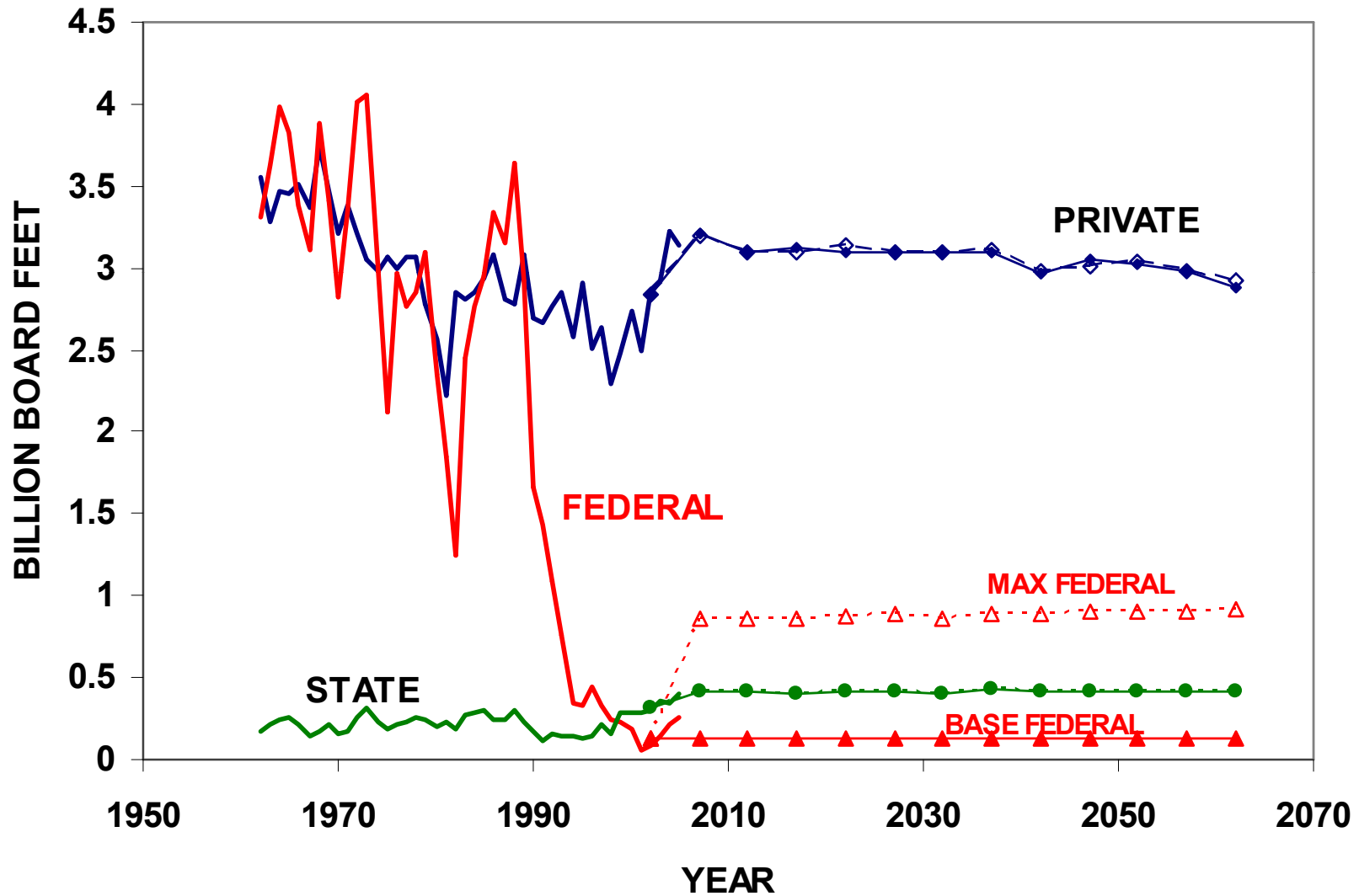
How well does our carbon accounting work?

□ **Comparison of current carbon stock (tonnes/ha)**

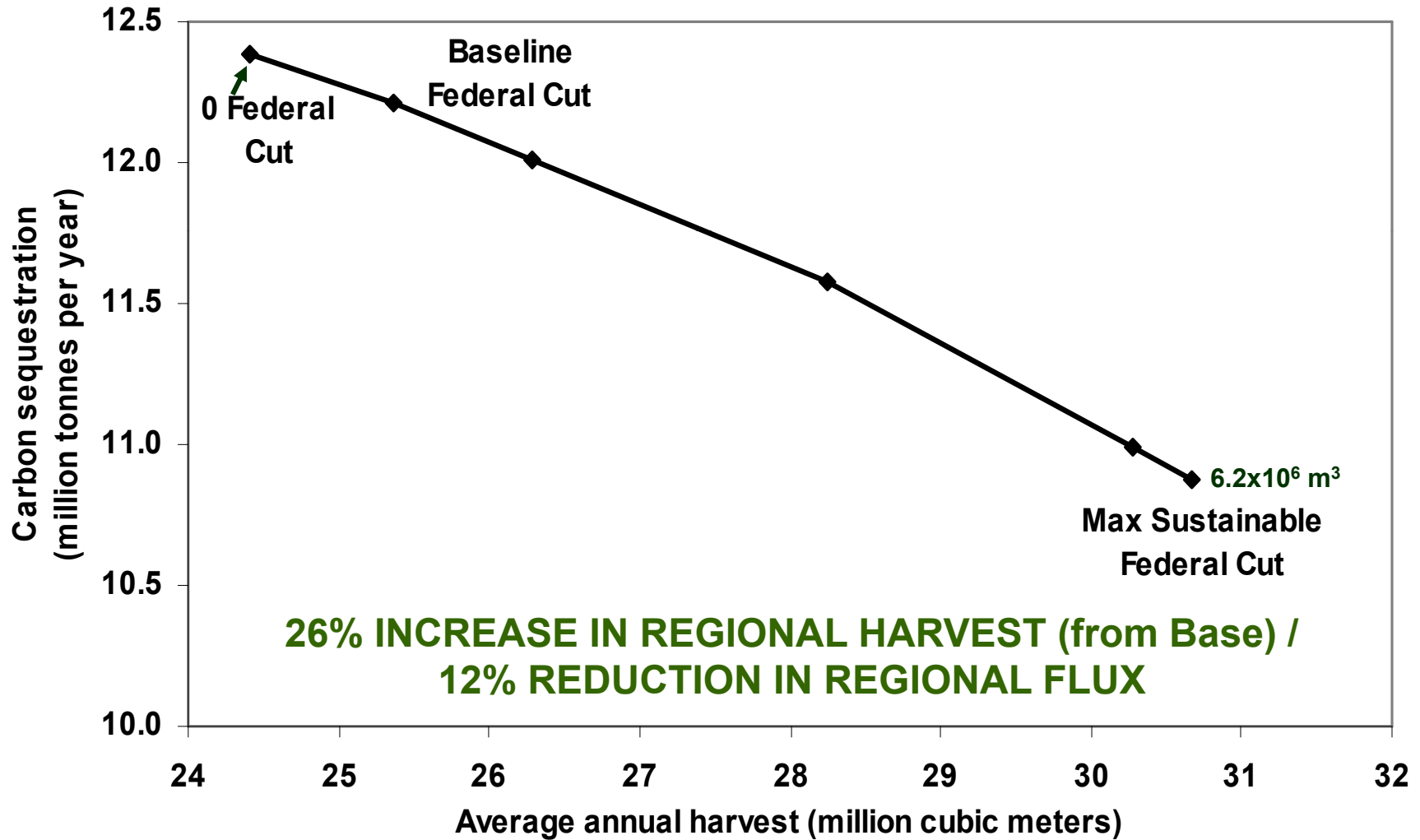
	Region/ owners	Live Carbon	Dead Carbon	Product Carbon
Heath et al. ('03)*	PNW/all	102.8	45.6	-
Birdsey & Lewis('03)*	OR/all	82.3	42.4	26.4
Law et al. ('04)†	WOR/all	128.6 - 196.8	38.4 - 49.5	-
This study †	WOR/all	144.2	39.5	38.2
	/Private	82.7	35.3	61.0
	/USFS	204.9	45.3	19.8
	/OPUB	161.4	34.1	21.9
	/State	176.2	48.3	26.5

Note: * Estimate of carbon stock in 1997; and † carbon stock in 2002.

HISTORICAL AND PROJECTED HARVESTS: CURRENT AND MAX FEDERAL CUT



Results: Regional Carbon Flux and Harvest Impacts of Expanded Federal Cut

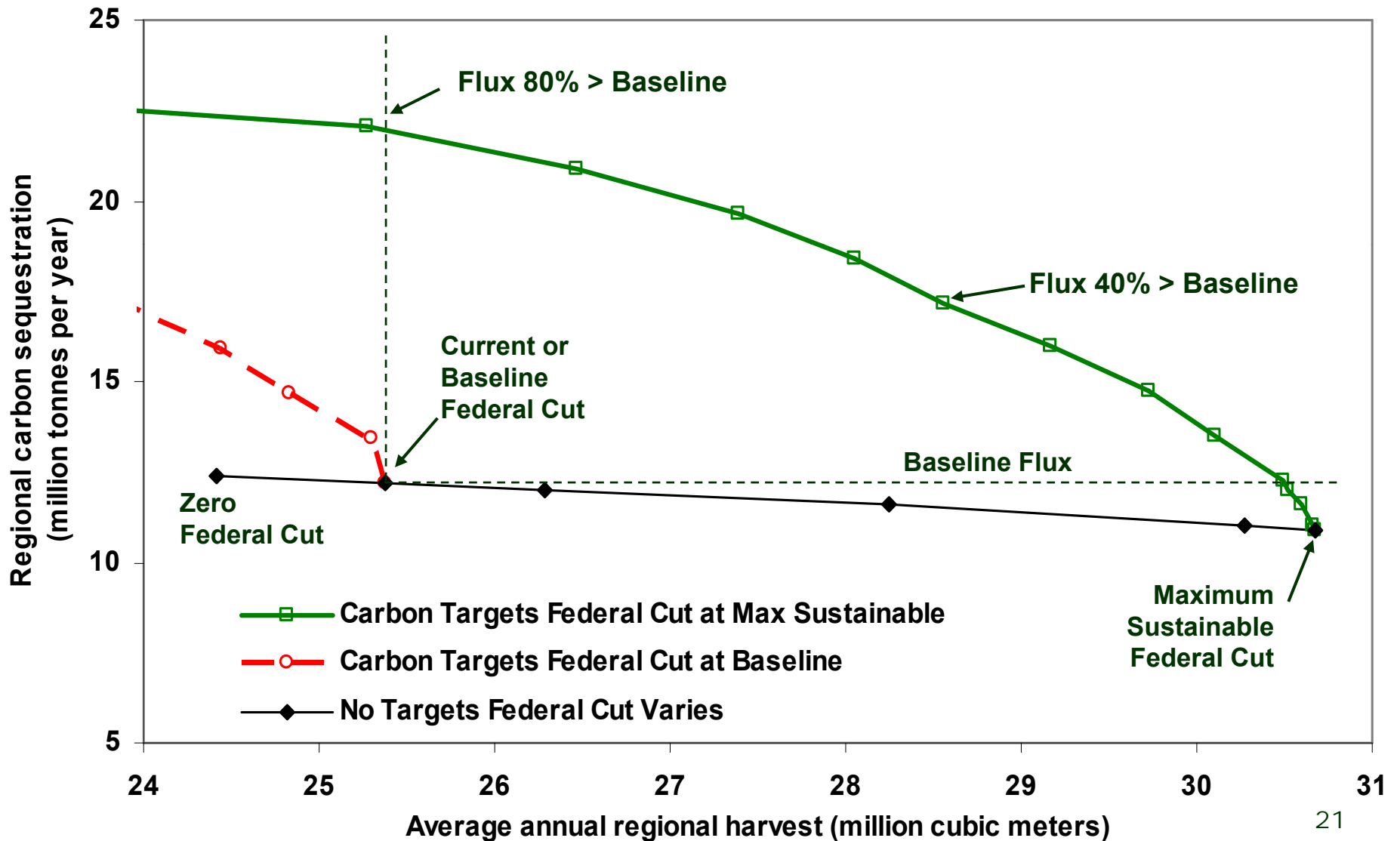




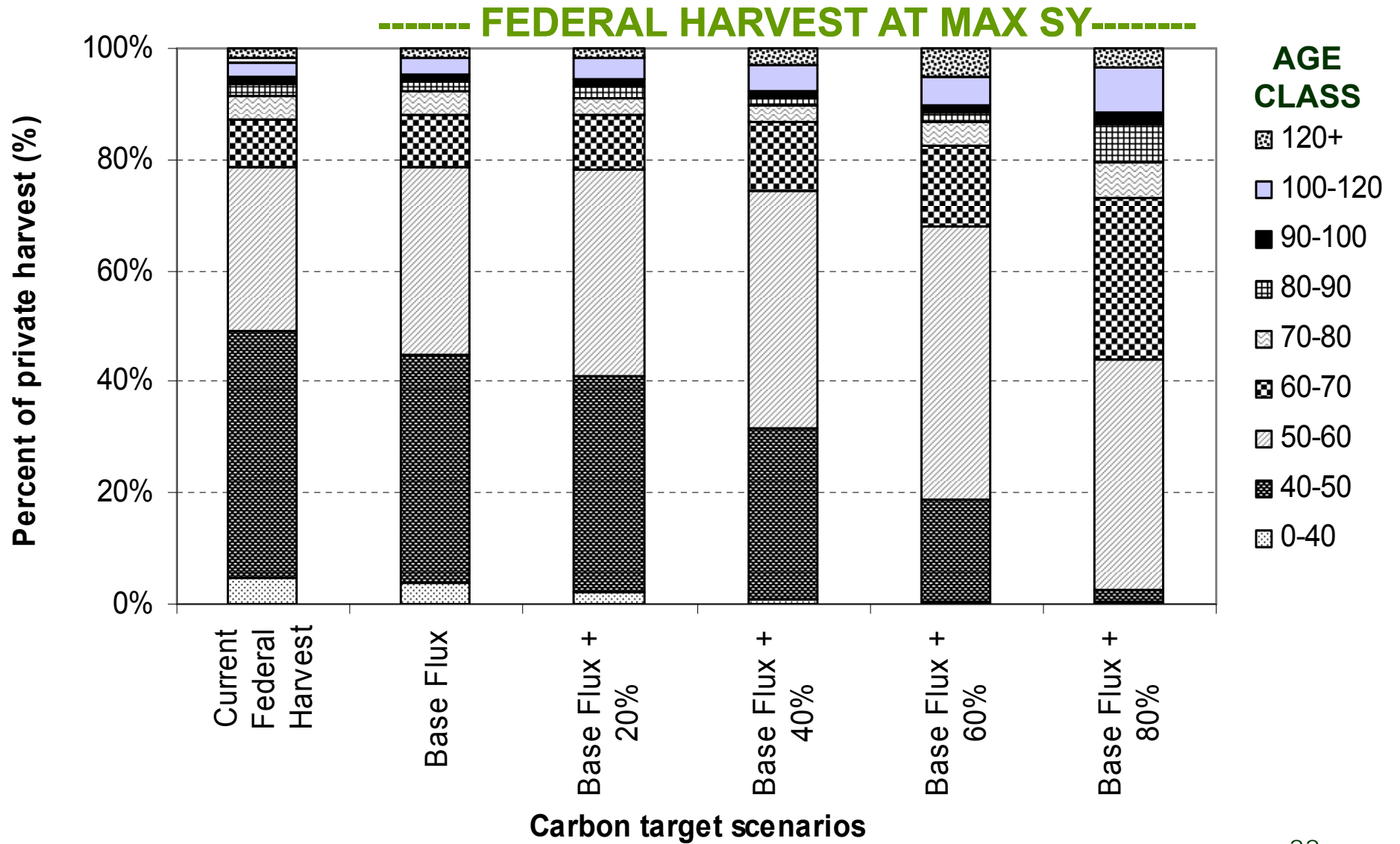
Results: Harvest Projections--current and maximum federal harvest



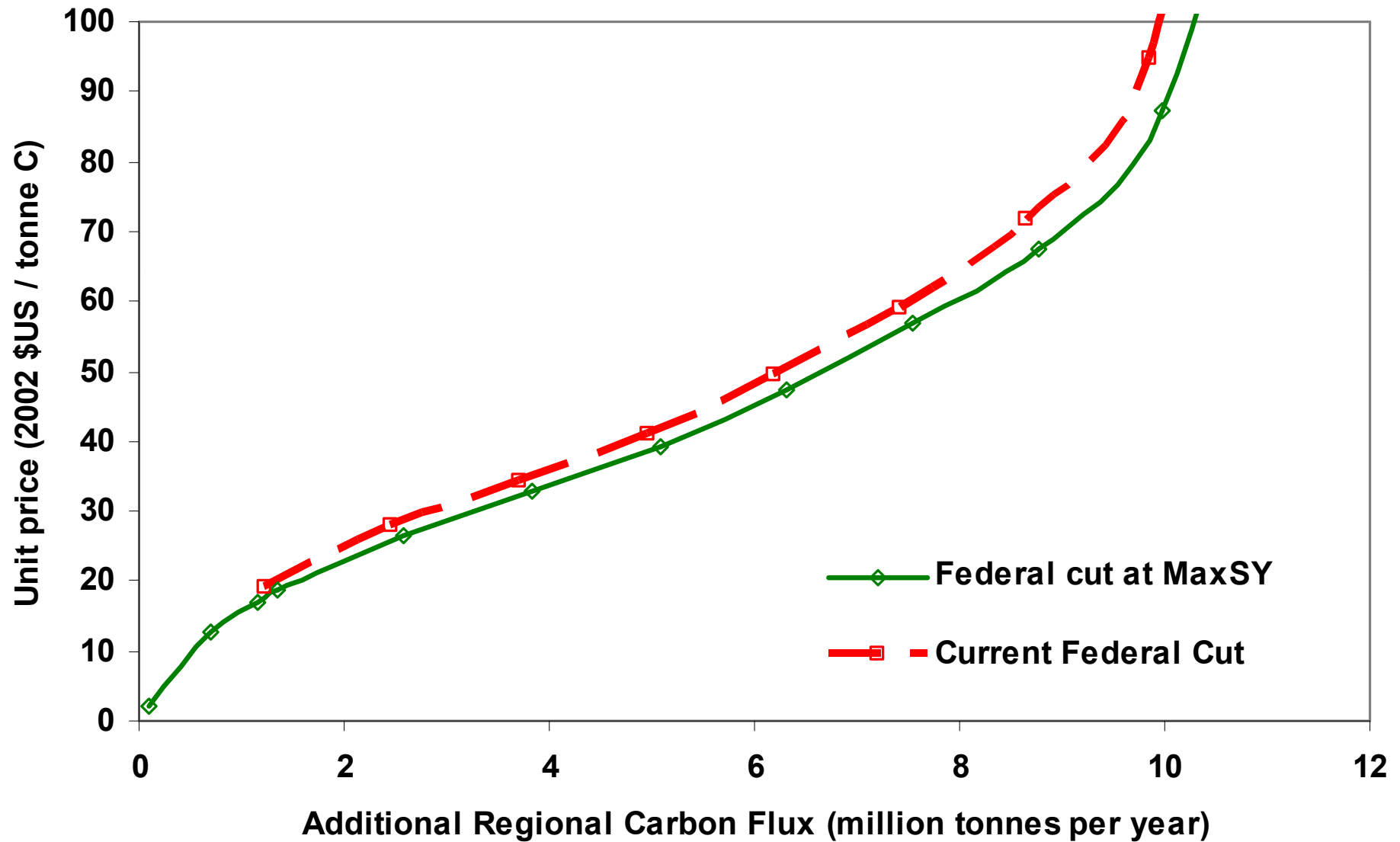
Harvest And Carbon Flux Trade-off For Various Regional Carbon Targets And Two Alternative Levels Of Federal Cut



Results: Concentration of Private Cut by Age Class



MARGINAL COST OF ADDITIONAL REGIONAL FLUX FOR TWO LEVELS OF FEDERAL CUT





Summary

- Regional carbon flux declines as federal harvest rises
 - $-12\% \Delta \text{ flux} / +28\% \Delta \text{ harvest} \rightarrow -0.4$ elasticity
 - Little price or private harvest response to federal changes
 - Capacity adjustments
- Significant opportunities for substituting harvest and carbon flux between federal and private/state lands
 - Composition of federal cut changes little with flux targets
 - Constrained by NWFP
 - Flux adjustments all come on private lands
- Implementation: carbon subsidy/tax mimics regional carbon flux target
 - At max federal sustained yield \$19/tonneC tax produces current flux





Log Demand

- **Demand equations (lumber and plywood)**
 - **Estimate at regional level, disaggregate to mills**
 - **Normalized, restricted quadratic profit function approach**
 - **Lumber output and log, labor and “all other” factor inputs**
 - **Capital stock quasi-fixed, measured by “output capacity”**
 - **Log price endogenous, lumber and other factor prices predetermined**
 - **Estimate system: profit, supply, and two factor demand relations**
 - **Impose symmetry and convexity**
 - **Lumber estimated as differences to avoid nonstationarity concerns**
 - **Iterative 3SLS**

LOG DEMAND = D[LOG PRICE, PRODUCT PRICE (INCLUDING CHIPS), LABOR PRICE, TIME, CAPACITY]

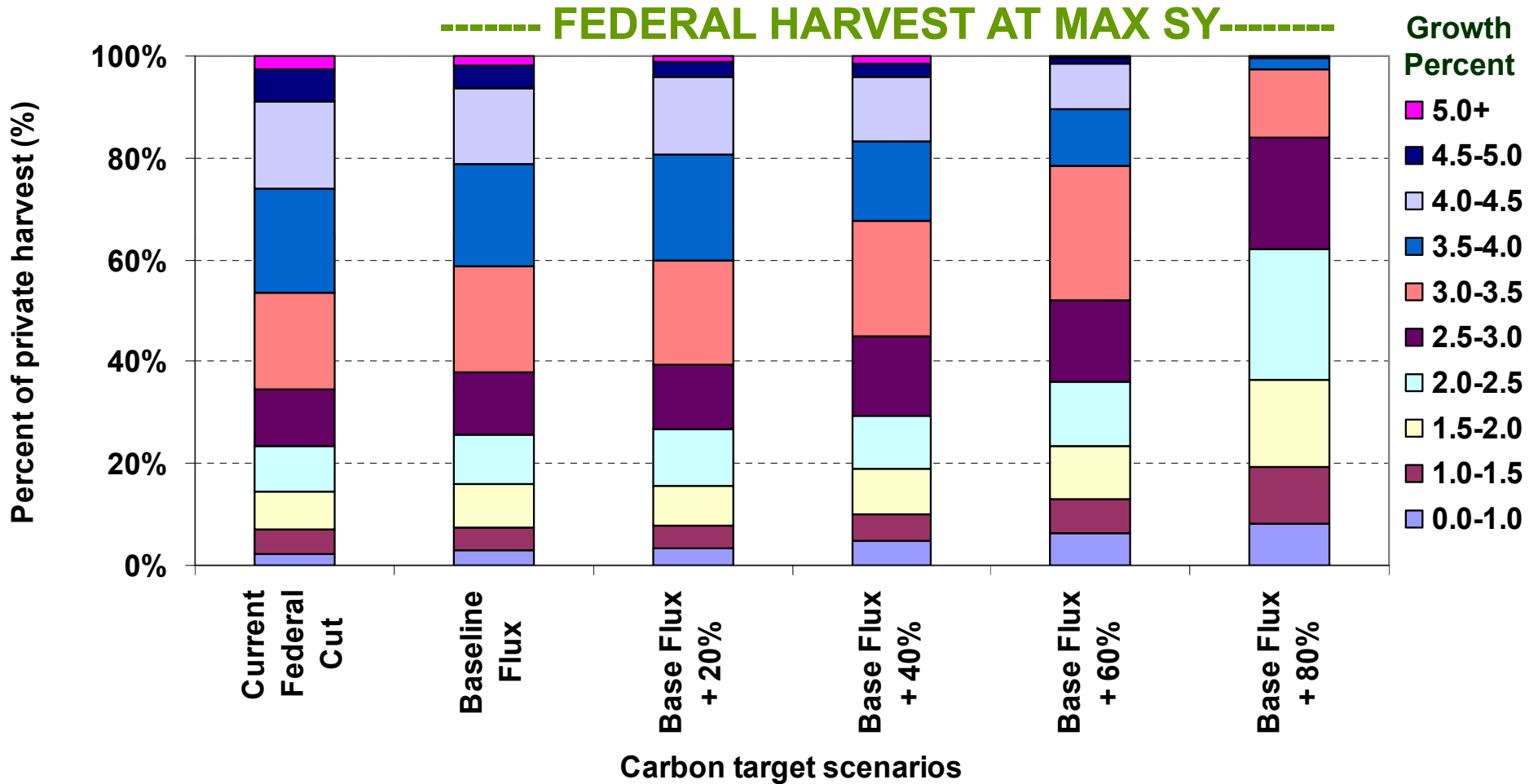
- **Log demand elasticities at sample means: -.47 for lumber, -.72 for plywood**



Overall Model Structure: Constraints

- (2) All “plots” (condition classes) must be allocated to some MIC in each period
- (3) Even-aged planting \leq area harvested in new and existing even-aged stands each period
- (4) $\text{Harvest}_{\text{PLOTS}} = (\text{Final Harvests} + \text{Thinnings})_{\text{EVEN-AGED AREAS}} + (\text{Partial Cuts})_{\text{UNEVEN-AGED AREAS}}$
- (5) $\text{Harvest}_{\text{PLOTS}} \geq \sum_{\text{MILLS}} \text{Shipments}_{\text{PLOTS, MILLS}} + \text{Exports}_{\text{PLOTS}}$
- (6) $\sum_{\text{PLOTS}} \text{Shipments}_{\text{PLOTS, MILLS}} + \text{Imports} + \text{Public} \geq \text{Receipts}_{\text{MILLS}}$
- (7) $\text{Receipts}_{\text{MILLS}} \leq \text{Capacity}_{\text{MILLS}}$
- (8) $\text{Capacity}_{\text{MILLS}} = \text{Capacity}_{\text{MILLS, TIME-1}}(1-\delta)^5 + \text{Maintenance}_{\text{MILLS}} + \text{Expansion}_{\text{MILLS}}$
- (9) Convexity Constraints (piece-wise linearization of area under demand functions)
- (10) Non-negativity

Results: Concentration of Private Cut by Carbon Growth Rate





LOG SUPPLY

■ PRIVATE LANDS

- ACT AS LAND VALUE MAXIMIZERS (GIVEN PRICES)
- ENDOGENOUS SELECTION OF FUTURE SILVICULTURAL REGIME AT TIME OF REGENERATION
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