THE INFLUENCE OF PARAMETRIC UNCERTAINTY ON PROJECTIONS OF FOREST LAND USE, CARBON, AND MARKETS

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OUTLINE

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MOTIVATION

- Forestry models parameterize physical and economic conditions over time, but many factors make these parameters uncertain.
- There is still a lot of variation in future projections of forest land and carbon stocks in part due to assumed forest growth and land supply parameter assumptions.

BACKGROUND

- Much focus on of the sensitivity of forest outcomes to economic conditions, bioenergy policies, carbon pricing, and climate change, but relatively less on uncertainty in underlying physical characteristics.
- Historically, carbon outcomes across the world have been influenced by two important drivers that are most affected by these parametric assumptions: land use change and forest regrowth (IPCC, 2014).
- These factors will continue to be important for future carbon outcomes so important to understand the uncertainty underlying baseline forest sector projections.

GLOBAL TIMBER MODEL (GTM)

- Based on earlier TSM and GTM (Sedjo and Lyon, 1990; Sohngen et al., 1999).
- An intertemporal economic optimization model
- Includes representation of 175 forest types around the world, and a 150-year time horizon
- Global timber demand is exogenous and driven by population, income and technology change.
- Dynamic forests: timber and pulpwood production determined by optimization over forest age classes, area of accessible and inaccessible land, planting, and management intensity.
- Prices endogenously determined.
- Land demand driven by agricultural markets, but exogenous to model (rents exogenously specified).

MONTE CARLO APPROACH

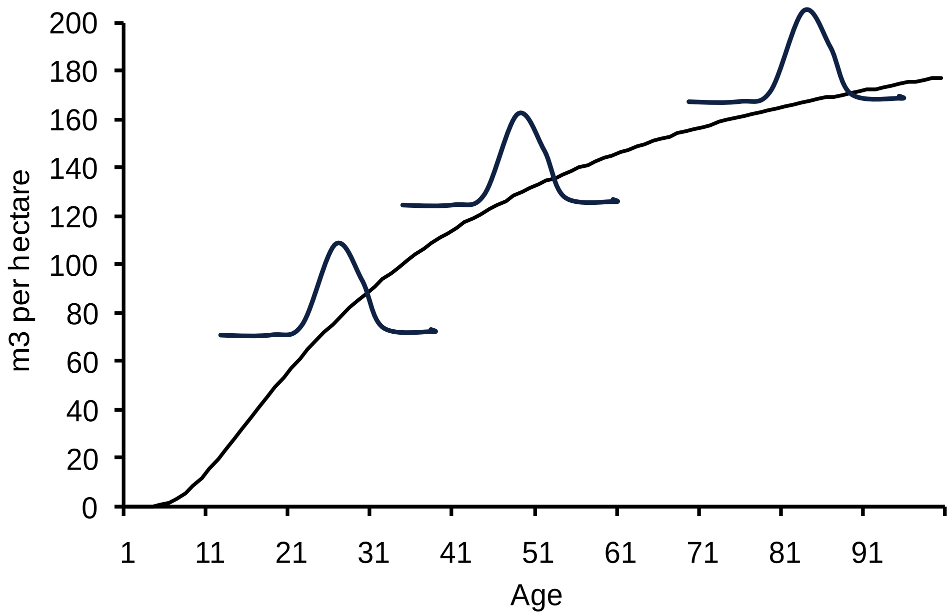
- Varied four parameters across two functions –the yield function, and the land supply function.
- Performed 300 trials (277 solved).
- Rental functions are forest type-specific and each forest type receives an independently drawn set of yield function and land supply parameters.
- The land supply function is recalibrated for each parameter draw.

YIELD FUNCTION

- Forest biomass yield function:

$$Y_{a,t}^{i} = e^{\left(\delta_i - {}^{\pi_i}/_{a}\right)}$$

- The yield function measures the volume of timber available for markets in land class *i* and age class *a* at time *t*.
- The term δ_i measures the carrying capacity of the site, and π_i accounts for forest growth.
- *We stochastically vary the parameters* $\boldsymbol{\delta_i}$ *and* $\boldsymbol{\pi_i}$*, according to a triangular distributions.*

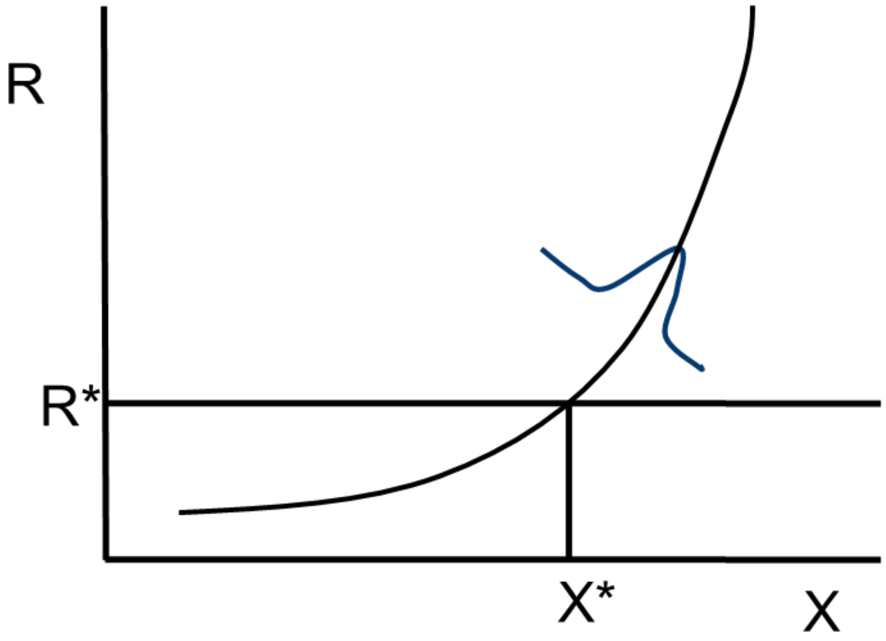


LAND SUPPLY FUNCTION

- The land supply function for each timber type, *i*, is:

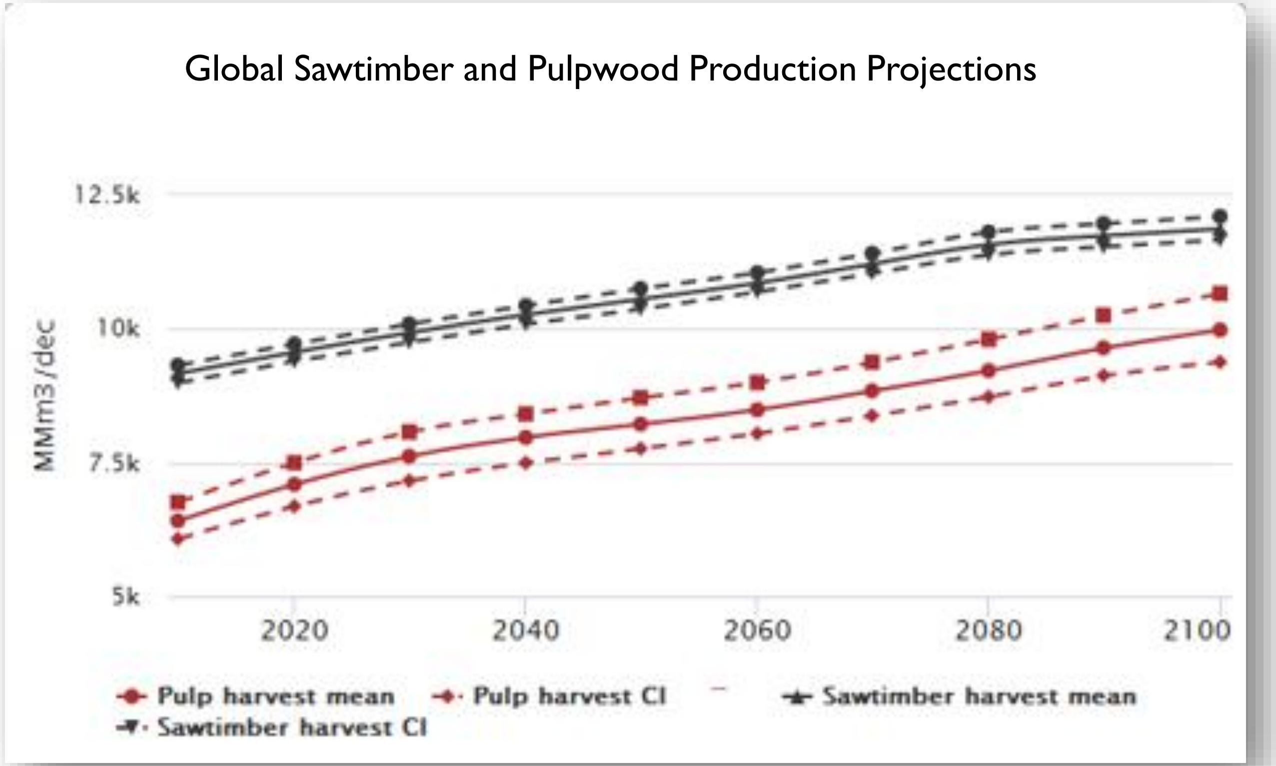
$$\sum_{a=1}^{A} X_{a,t}^{i} = A_t^i (L_t)^{(1/\gamma)} \left(R_t^i\right)^{\eta_i}$$

- total area of land in forests in each timber type i, is the sum of the area in each age class, $X^i_{a,t}$, as a function of the rental rate, R^i_t.
  - A^i_t is a slope parameter that changes over time to reflect shifts in the demand for land in the agricultural sector.
  - L_t=ratio of current global land in forests to original land in forests
- *We stochastically vary the parameters* $\boldsymbol{\eta_i}$ *(the own-price elasticity of supply), and* $\boldsymbol{\gamma}$ *(the price elasticity of global forestland supply) according to triangular distributions.*



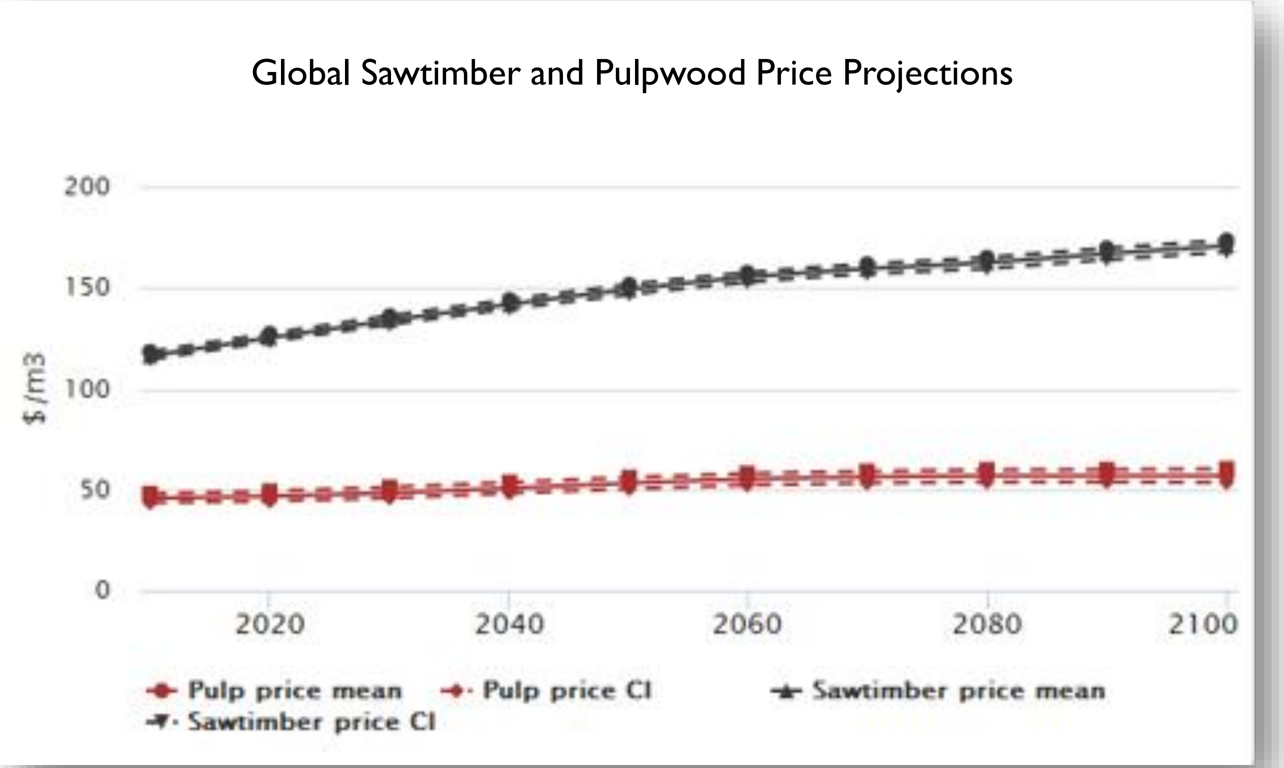
RESULTS
PRODUCTION PROJECTIONS

- Global sawtimber and pulpwood production increases over the century, with pulpwood output increasing slightly more rapidly over time.
- Larger variation in pulpwood outputs than sawtimber.
- Pulpwood is the lower value output, and some pulpwood cannot substitute into sawtimber markets.

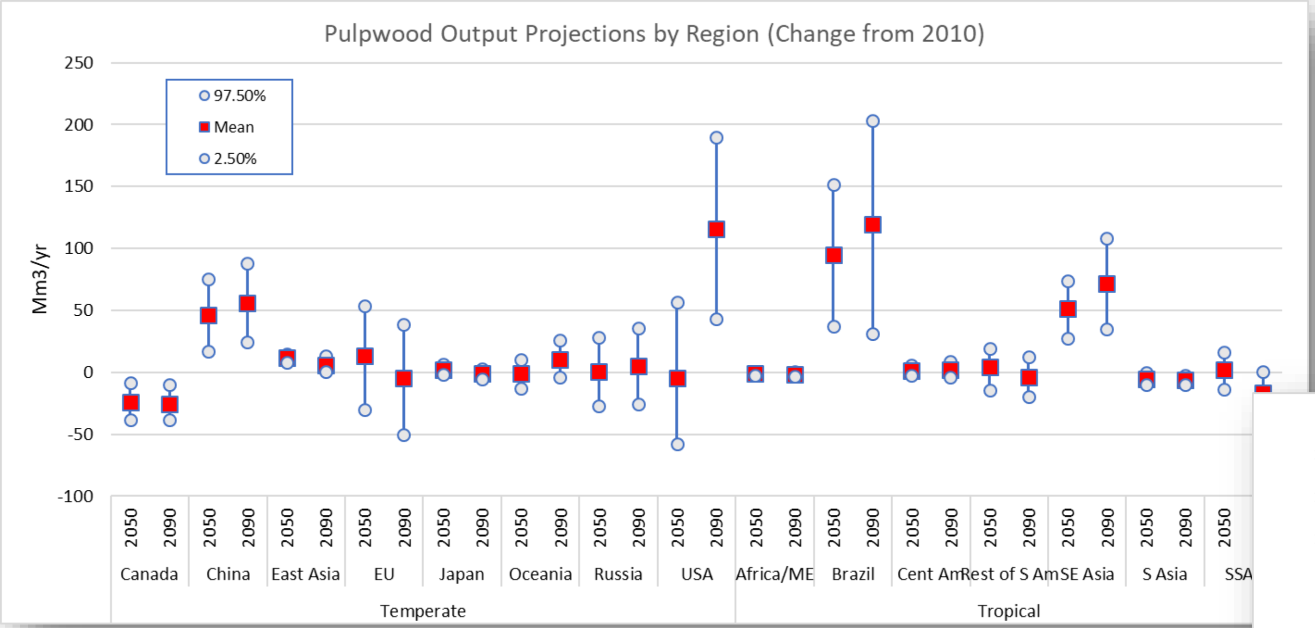


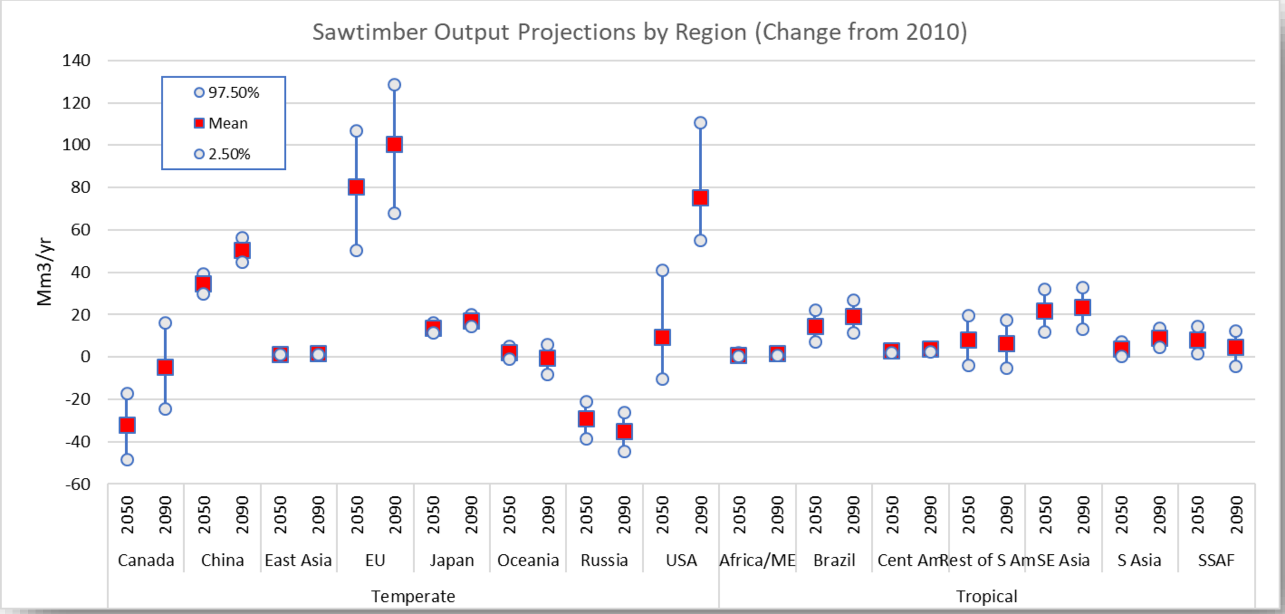
RESULTS
PRICE PROJECTIONS

- Sawtimber prices rise more rapidly over the century given the higher value of sawtimber products and that the marginal cost of extracting additional sawtimber are higher than the marginal cost of extracting additional pulpwood.
- The uncertainty bounds on prices are small. Through 2100…
  - Sawtimber price bounds: <4% of mean sawtimber price
  - Pulpwood price bounds: <12% of mean pulpwood price
- Wood outputs from various regions are highly substitutable in the demand function, so parametric deviations in supply through the yield functions or rental functions have little impact on aggregate price, or output.

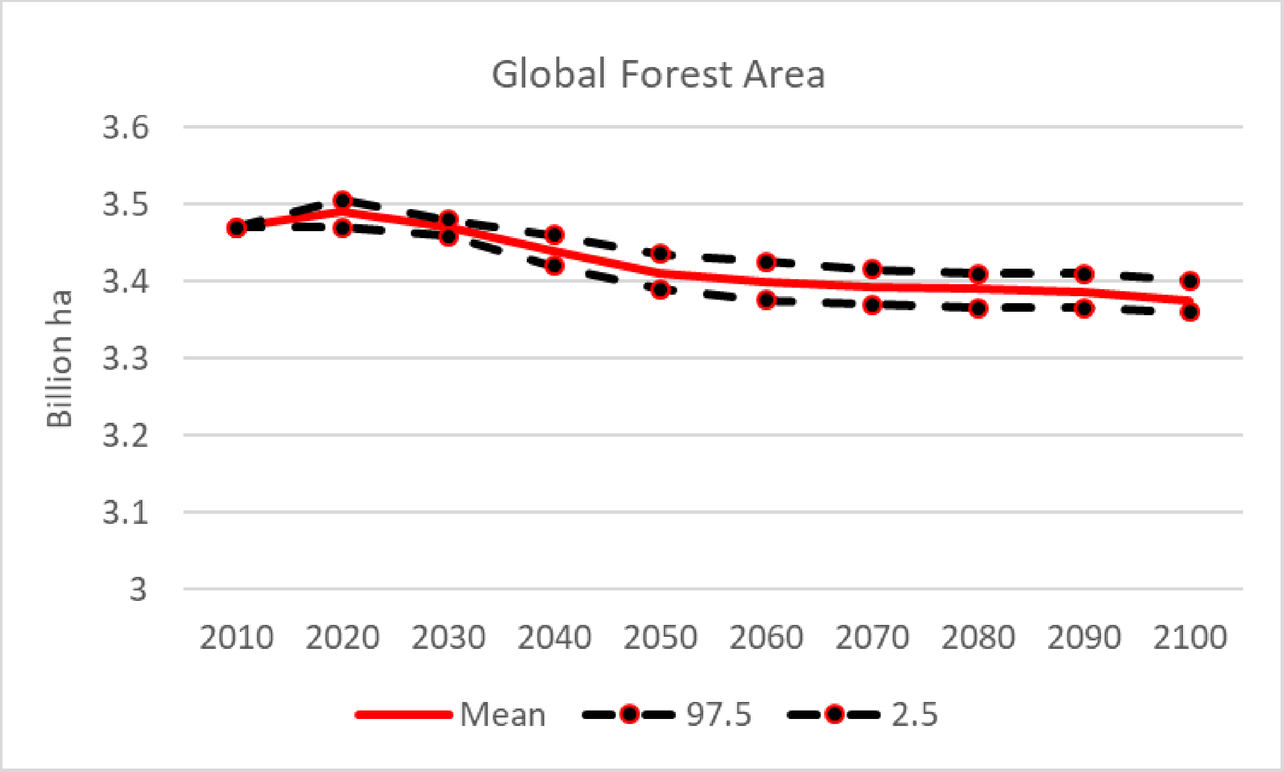


RESULTS
PRODUCTION BY REGION





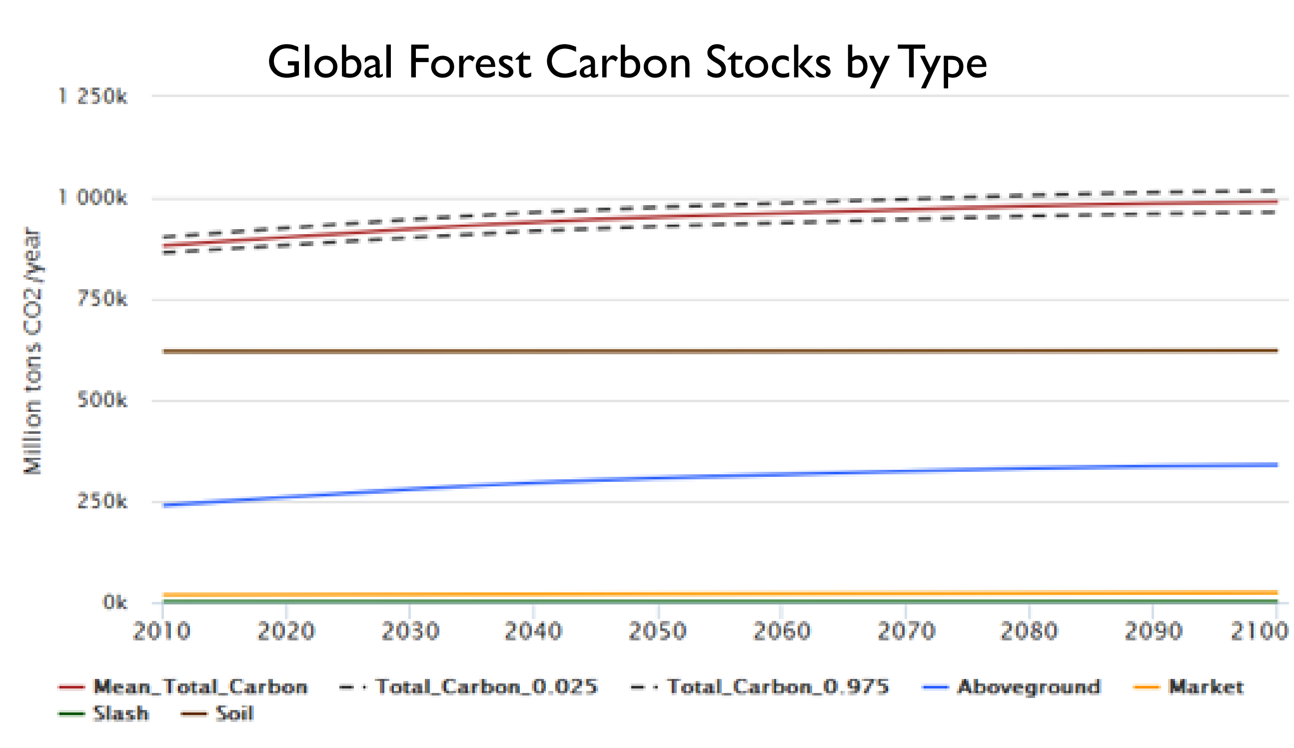
RESULTS
GLOBAL FOREST AREA



- Over the projection period to 2100, the total forest area declines by around 100 million hectares.
- The 95% uncertainty interval is 1.5% of the total forest area. Our parameter variability has little effect on global land area in forests.
- Globally, the aggregate change in forestland area is influenced mostly by assumptions about the underlying factors driving land use change, such as the demand for agricultural land.

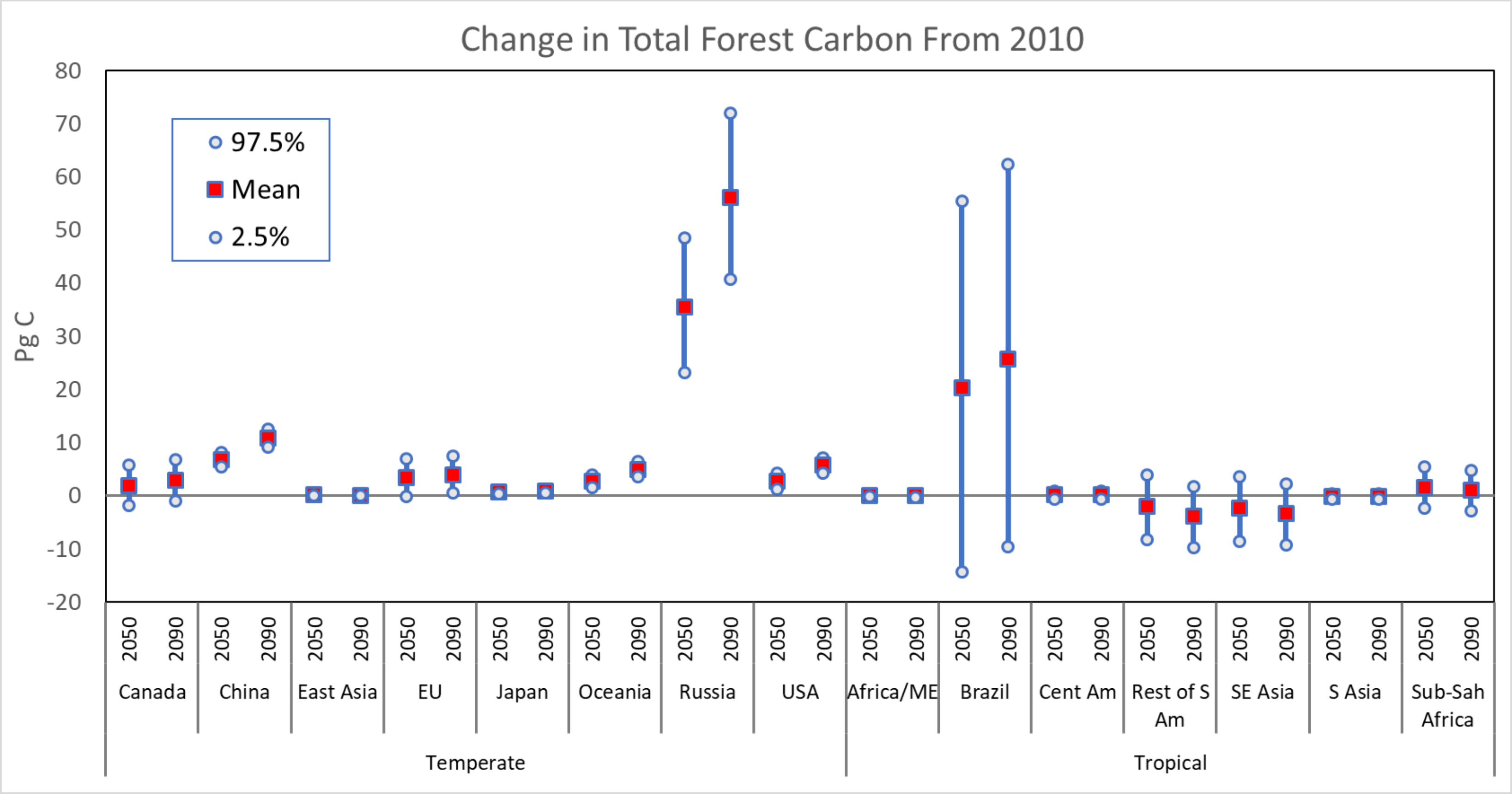
RESULTS
GLOBAL FOREST CARBON STOCKS

- Total forest carbon storage increases in the baseline ranging from -5.0 to 149.1 Pg C by 2050 and 24.8 to 186.6 Pg C by 2090 representing an increase of 3.3% - 23% in 2090 relative to 2010 levels.
- The bulk of carbon is stored in soil components while the largest change in carbon occurs in the aboveground portion. The 95% uncertainty range for aboveground C represents around 8% of the average aboveground carbon.
- The 95% range for total carbon storage is relatively small (+/- 2.5%), in part because
  - soil carbon is assumed to be relatively stable and we do not assign uncertainty to the parameters determining the soil component.
  - sawtimber harvests do not vary extensively (thus market carbon remains consistent),



RESULTS
REGIONAL FOREST CARBON STOCKS

- Brazil increases carbon storage on average while at the same time losing land to deforestation as regeneration and growth on existing forests outweighs the losses due to deforestation.
  - This outcome is heavily influenced by uncertainty in parameters in Brazil, given the relatively large potential for carbon losses shown by the 95% uncertainty range.
- The large increase in forest carbon stocks in Russia largely occurs on forests remaining forests in eastern Russia (i.e., Siberia) mainly as currently young forests increase in age.

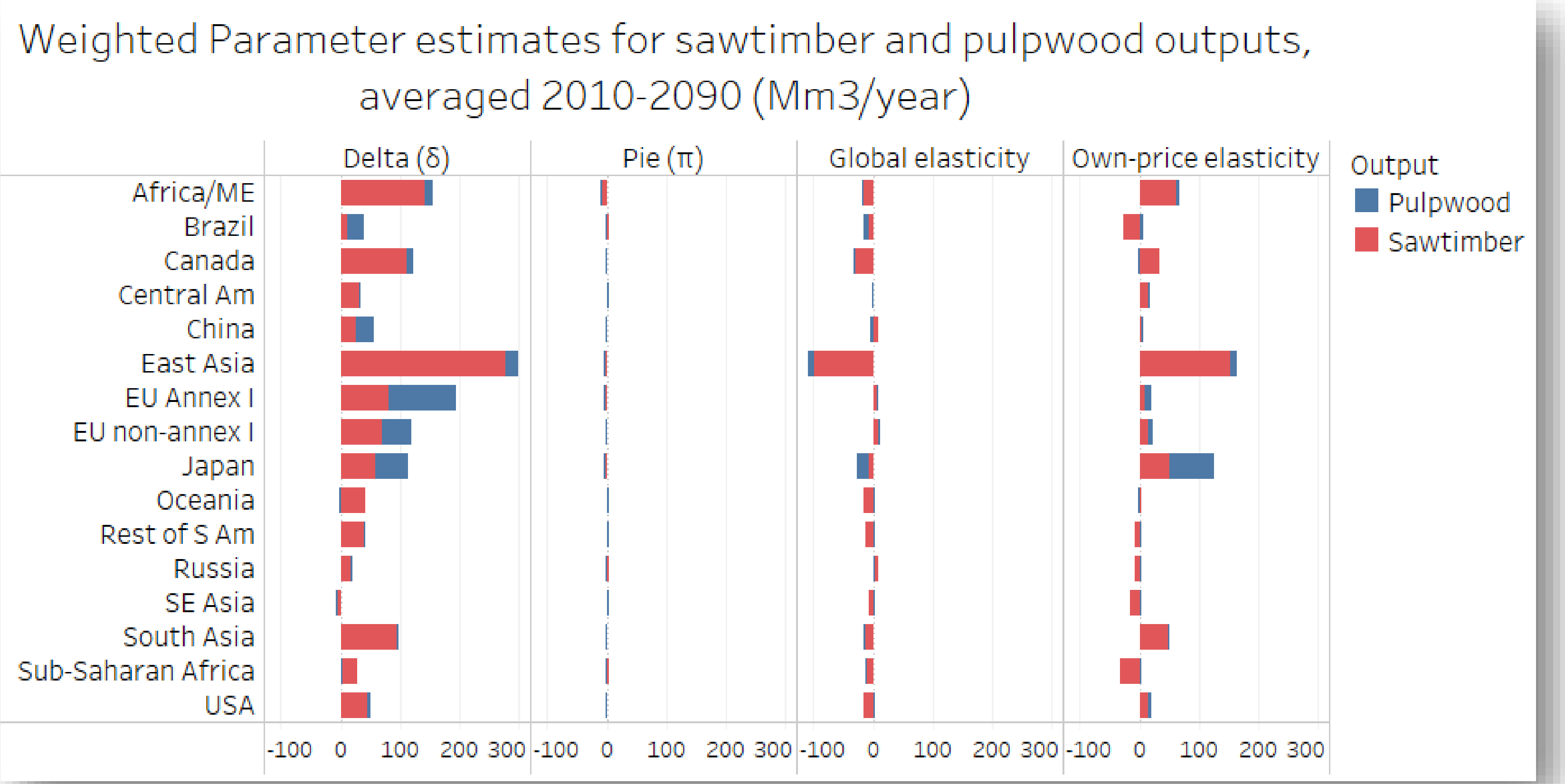


ATTRIBUTIONAL ANALYSIS

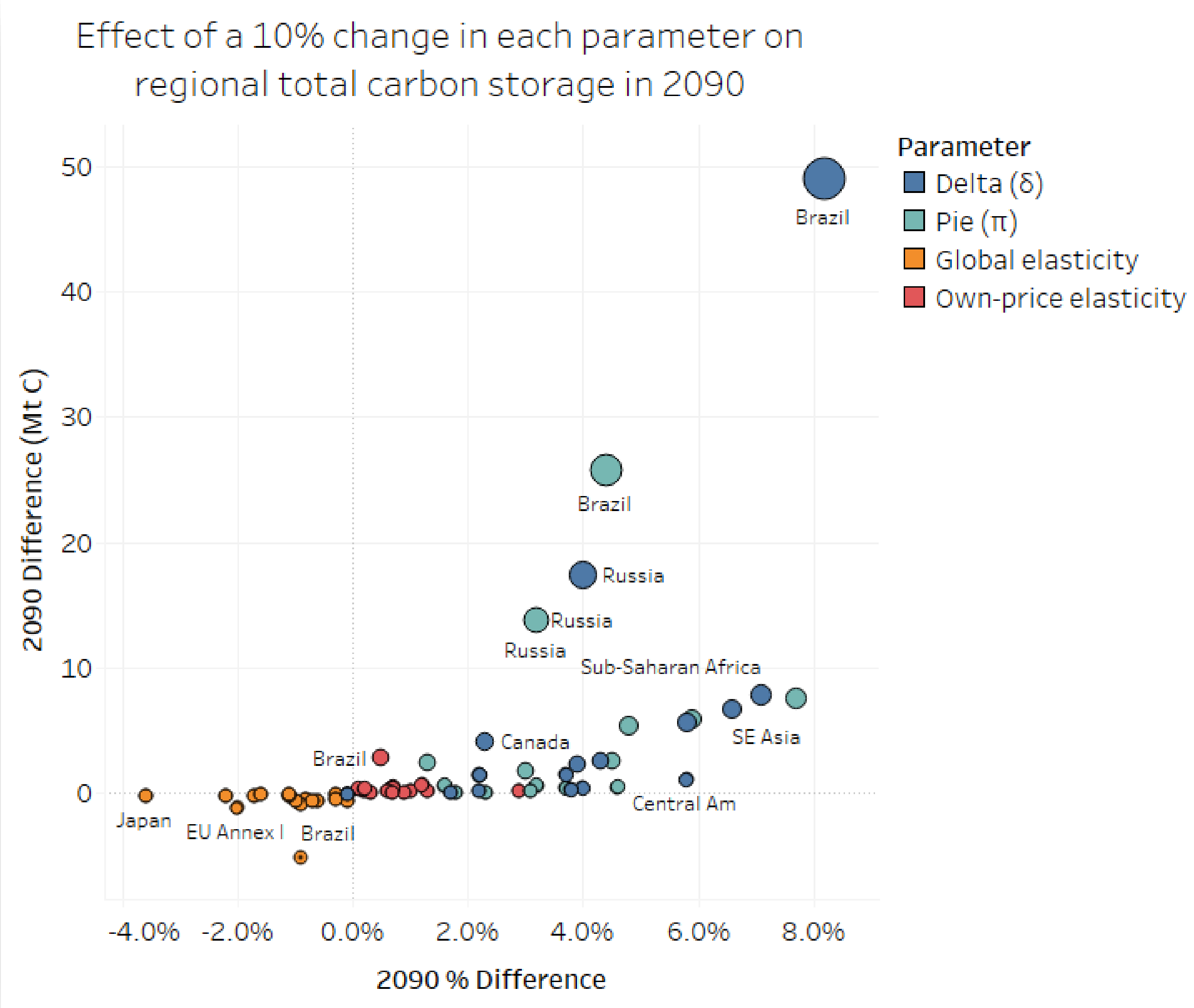
- Relatively large uncertainty in carbon outcomes in carbon intensive regions like Brazil, but unclear if the uncertainty is derived from the parameters of the growth function or the parameters of the land supply function.
- Understanding which set of parameters has the largest impact on timber output or carbon may be most important in regions facing large land use change.
- Apply a spatial weighting procedure and use regression analysis to assess the relative importance of the GTM's stochastic parameters on markets and carbon projections by region.

ATTRIBUTIONAL ANALYSIS RESULTS
TIMBER AND PULPWOOD OUTPUTS

- Greater stocking density (+δ) is associated with greater output, as is higher yield growth (-π) (that relationship is modest)
- The impact of the global land supply parameter (γ) is generally negative on outputs, as a higher gamma means it is costlier to hold land in forests, so would expect lower outputs.
- regional own-price elasticity (η) is mostly positive, as higher eta shifts land supply function out, making it cheaper to enter new forests at given rental rate



ATTRIBUTIONAL ANALYSIS RESULTS
CARBON



- The stocking density and yield growth correspond to greater carbon storage as expected, with one exception (Japan).
- We find that the magnitude in deviations in carbon storage related to physical parameters are far greater than those related to elasticity parameters.

SUMMARY

- Using a super computer we performed a Monte Carlo analysis with a global dynamic optimization model to test the sensitivity of market outcomes (e.g., prices, outputs) and carbon to variation in assumed biomass yield function and land supply input values.
- The results suggest that aggregate market trends are not significantly affected by uncertainty in the underlying parameters for forest yield or land rents. Prices are expected to increase modestly both for sawtimber and pulpwood, but the uncertainty bounds for both are small.
- Global carbon storage is expected to increase by 71.7 Pg C (-5.0 to 149.1) by 2050 and 104.9 Pg C (24.8 to 186.6) by 2090.
  - Most regions are expected to increase forest carbon storage, with the biggest increases on average occurring in Russia and Brazil.
  - In the tropics, there is more potential for carbon losses over time, due to continuing deforestation trends.
- We include an attributional analysis to assess relative importance of the varied parameters on outcomes
  - carbon impacts are unambiguous: higher biomass carrying capacity increases carbon storage, as does faster growth; these effects dominate those from changes in elasticity values.

THANK YOU!

QUESTIONS?

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ATTRIBUTIONAL ANALYSIS OVERVIEW

- We start by estimating regression equations for each forest land class in the model.

$$Regional\_Effect_n = \sum_{m=1}^{L} w_m * \beta_{mn}$$

- where:
  - m = 1, …L are forest types for a given region
  - n = stochastic parameters as previously defined
  - w_m = forest land class m weight and is computed as $w_m = \frac{\sum_{t=1}^{T} A_{mt}}{\sum_{t=1}^{T} \sum_{m=1}^{L} A_{mt}}$ where A_{mt} is the area of forest land class m in time t
  - β_{mn} = estimated coefficient value for forest type m and stochastic parameter n
- The dependent variables in the regression equations are cumulative projected harvests of sawtimber and pulpwood, and carbon stocks in the 2050 and 2090 simulation periods, all represented at the land class level.
- Explanatory variables in the regression models include a constant term, plus estimated coefficient values for δi and π_i, the own-price elasticity in the rental function for each land class, and the global land supply elasticity.

DATA

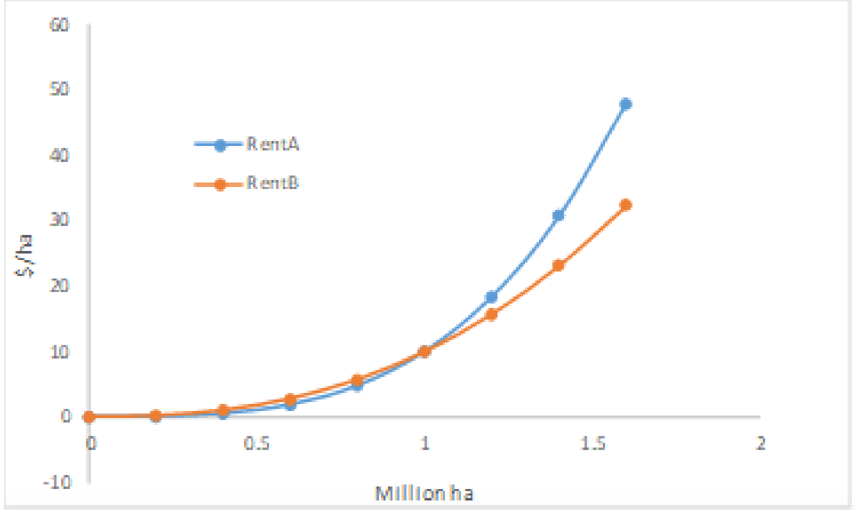
- Forest Area and Inventories

Region	Data Source
United States	US Department of Agriculture, Forest Service. Various years. Forest Inventory and Analysis (www.fia.fs.fed). Data retrieved from 2014 FIA report
Europe	Kuusela (1993)
Russia	Russia: Forest Account (2004)—See Sohngen et al. (2005) for a discussion of this data.
Canada	Lowe et al. (1994); Updated with Canada's National Forest Inventory in 2010. See: https://nfi.nfis.org/hom.php
Australia	Australian Dept. of Agriculture and Water Resources, Bureau of Rural Sciences (2003); Australian Bureau of Agricultural and Resource Economics (1999)
New Zealand	New Zealand Ministry of Agriculture and Forestry (1987).
China	China (Ministry of Forestry, Center for Forest Inventory)
All other countries	UN FAO (2005, 2010, 2015)

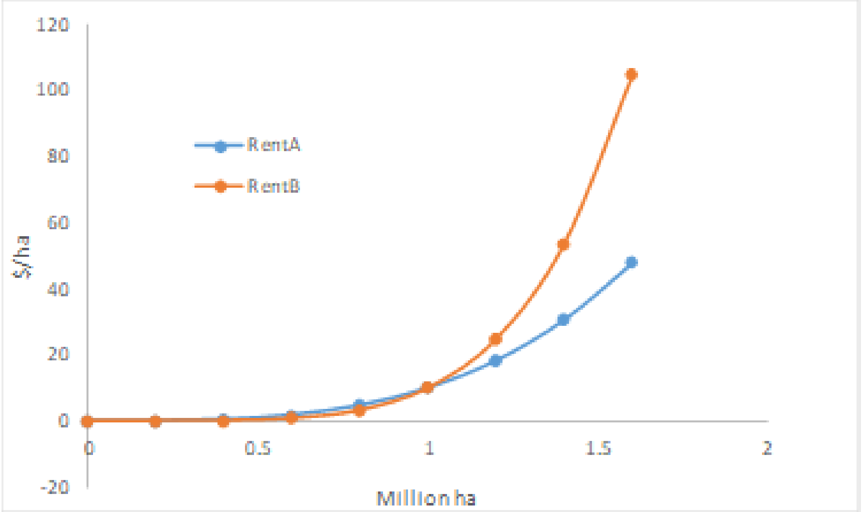
ADJUSTMENTS TO *OWN PRICE ELASTICITY* PARAMETER

- Adjustments in rental function when own price elasticity is adjusted. Comparison of η=0.3 in RentA to η=0.4 or 0.2 in RentB.
- An increase in η flattens the rental function, and a reduction in η makes the rental function steeper.
  - note that the rental function has the same value at total land area of 1.0, which would be equivalent to 1 million hectares in the model.
  - The effect of the adjustment in the own price elasticity parameter on rents will thus differ depending on whether the region has more or less than 1 million ha of forests.

η = 0.4



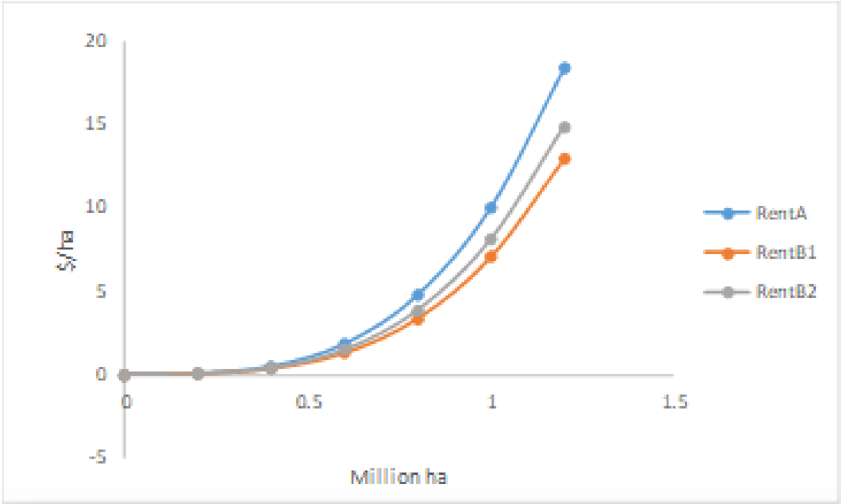
η=0.2



ADJUSTMENTS TO *GLOBAL LAND SUPPLY ELASTICITY* PARAMETER

- Adjustments in rental function with adjustments in the global land supply elasticity.
- the rental function in period 1 is RentA, with γ=0.3 and in period 2 when L_t = 0.9 under the original elasticity when γ=0.3 in RentB1 and an adjusted elasticity when γ = 0.5 in RentB2.
- An increase in elasticity shifts the rental function upward while a reduction in elasticity shifts the rental function downward.
  - In this case, in period 2, L=0.9, and the global adjustment factor is 0.70 when γ=0.3 and it is 0.81 when γ=0.5.
  - Conversely when γ=0.2, the global adjustment factor is 0.59, and the rent function is lower.

γ = 0.3 in RentA & RentB1 and 0.5 in RentB2



γ = 0.3 in RentA & RentB1 and 0.2 in RentB2