# Ecosystem services production efficiency of longleaf pine under changing weather conditions


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## Introduction

1) Southern US forests forest dominate the landscape and provide critical ecosystem services:

- 87 million hectares, 28% of total US forestlands
- provide 2/3 of the timber harvested in the US
- potential to sequester nearly 1/4 of the region's greenhouse gas
- produce 34% of the water yield in the region
- host >1,000 native terrestrial vertebrate species

2) The provision of these forest ecosystem services may be at risk from changing weather conditions:

- decrease in water availability
- increase losses in species extinction
- increase in frequencies of fires, pests, winds
- However, the productivity of forestlands may be benefited with higher concentrations of CO2

3) Forestry: a well-known example of a joint production process in which the supplies of ecosystems services are interlinked

- e.g. planting more trees per area: more C sequestration and pulpwood production reducing the availability of water for streamflow

4) Analysis of the efficiency in use of natural resources provides critical information for the formulation of natural resource management and environmental policies

5) Efficiency: maximum amount of ecosystem services that can be produced given a combination of inputs)

6) We use a parametric approach to estimate the efficiency in the production of forest ecosystem services known as stochastic frontier analysis (SFA) in the Southern US

7) SFA from an output perspective, determines the maximum amount by which a joint-production of outputs can be expanded with a given input vector

## Objective

1) Assessment of the forest management on the efficiency performance in the joint production of timber, carbon sequestration, biodiversity, and water yield

2) We also analyze the effects of changing weather variables, age of the forests, and others on the production of ecosystem services

3) We select longleaf pine (*Pinus palustris* Mill) forests for our modeling context since they play a critical role in the provision of ecosystem services

## Methodology

1) SFA can be specified as follows:

$y_{Jit} = f(x_{it}, y_{it}, c_{it}; \alpha, \beta, \gamma) + v_{it} - u_{it}$

$u_{it} = \rho z_{it} + w_{it}$

$y_{Jit}$: $j$th output, unit $i$ (1,2,..,$N$) at time t (1,2..,$T$)

$x_{it}$, $y_{it}$: vector ok k inputs and m outputs

$c_{it}$ :vector of $l$ exogenous

$v_{it}$: N(0, $\sigma_v^2$); $u_{it}$: N+ ($\rho z_{it}, \sigma_u^2$)

$\alpha, \beta, \gamma$, $\rho$: vectors of unknown parameters

$z_{it}$ : vector of variables that explains the inefficiency $w_{it}$ : random variable (0, $\sigma^2$); $w_{it} \geq -\rho z_{it}$

2) We use longleaf pine plots (FIA data) in AL, *FL*, *GA*, *MS*, *NC*, and *SC*

3) We employ a translog function to model SFA

4) Historical (1950- 2005) temperatures and precipitation and future (RCP8.5; 2050-2100) obtained from MACA dataset

## Results

1) Translog functions are statistically significant (Table 1)

2) Most of the variation (around 90%) is attributed to differences in the efficiency to produce ecosystem services

3) Increased productivity of forests and tree density would reflect a decrease in the total production of ecosystem services.

4) Inherent tradeoffs in the concomitant production of forest ecosystem services

5) Joint production of ecosystem services is less efficient under private versus public owned longleaf pine forests

6) Forest plots with evidence of damage and silvicultural interventions tend to be more efficient

7) Technical efficiency is reduced by 8.9% with future weather conditions, ranging between 33.0% and 98.5%

8) Efficiency being reduced by 3.1% and 2.8%, respectively per 1 Celsius degree increase; however, for a 100-mm increment in precipitation, the efficiency is reduced by 7.6%

## Conclusions

1) SFA functional form employed is significant, indicating the presence of inefficiency in the production of ecosystem services

2) The technical efficiency in the concomitant production ecosystem services can be reduced on average by 8.9% with increased levels of temperatures and precipitation.

3) The production of certain ecosystem services may be reduced with increased forestry inputs

4) Silvicultural guidelines that favor the production of certain ecosystem services at the expense of others should be considered with a degree of caution.

5) Recognizing the production of ecosystem services as a bundle presents a challenge

6) Land managers and researchers must recognize the inherent tradeoffs between ecosystem services

7) Forest policy makers must explicitly consider landowners' objectives in the context of ecosystem services tradeoffs to develop socially-optimal forest management programs that appropriately incentivize the production of ecosystem services

**Table 1. Some of the parameter estimates of the SFA model**

| Parameter | Variable | Scenario A -Historical | | Scenario B -RCP8.5 | |
|---|---|---|---|---|---|
| Dependent variable $y_1$ | *Rich* | | | | |
| **Stochastic frontier** | | Coefficient | SE | Coefficient | SE |
| $\beta_0$ | Constant | -0.8000* | 0.0255 | -0.1371 | 0.1277 |
| $\beta_1$ | $ln\,Vol/Rich$ | -0.0355* | 0.0018 | 0.0251* | 0.0055 |
| $\beta_2$ | $ln\,Carbon/Rich$ | -0.0953* | 0.0045 | -0.3845* | 0.0130 |
| $\beta_3$ | $ln\,Water/Rich$ | -0.8654* | 0.0042 | -0.6076* | 0.0127 |
| $\alpha_1$ | $lnSite$ | -0.0746* | 0.0104 | -0.0943* | 0.0327 |
| $\alpha_2$ | $lnTree$ | -0.0383* | 0.0014 | -0.0221* | 0.0045 |
| $\alpha_3$ | $0.5 * lnSite^2$ | -0.0101 | 0.0373 | -0.3804* | 0.1010 |
| $\alpha_4$ | $0.5 * lnTree^2$ | -0.0161* | 0.0012 | -0.0138* | 0.0037 |
| $\alpha_5$ | $0.5 * lnSite * lnTree$ | 0.0412* | 0.0110 | 0.1002* | 0.0348 |
| $\alpha_6$ | $t * lnSite$ | 0.0023* | 0.0006 | -0.0023 | 0.0024 |
| $\alpha_7$ | $t * lnTree$ | -0.0005* | 0.0001 | 0.0015* | 0.0004 |
| **Heterogeneity** | | | | | |
| $c_1$ | $Tmin$ | -0.0012 | 0.0094 | 0.2009* | 0.0420 |
| $c_2$ | $Tmax$ | -0.0384 | 0.0286 | 0.0664 | 0.1209 |
| $c_3$ | $Pp$ | 0.8620* | 0.0065 | 0.2419* | 0.0290 |
| $c_4$ | $Age$ | 0.0240* | 0.0044 | -0.2503* | 0.0123 |
| $c_5$ | $AL$ | -0.0169* | 0.0034 | -0.1071* | 0.0133 |
| $c_6$ | $FL$ | 0.0156* | 0.0032 | 0.0041 | 0.0125 |
| $c_7$ | $GA$ | 0.0181* | 0.0029 | -0.0359* | 0.0099 |
| $c_8$ | $MS$ | -0.0308* | 0.0039 | -0.1163* | 0.0153 |
| $c_9$ | $NC$ | 0.0031 | 0.0032 | -0.0037 | 0.0110 |
| $c_{10}$ | $t$ | -0.0119* | 0.0034 | 0.0256*** | 0.0133 |
| $c_{11}$ | $t^2$ | 0.0042* | 0.0011 | 0.0130* | 0.0043 |
| **Inefficiency** | | | | | |
| $\rho_0$ | Constant | -4.3809* | 0.1370 | -4.9088* | 0.2769 |
| $\rho_1$ | $Own$ | 0.3460* | 0.0610 | 0.2641* | 0.0770 |
| $\rho_2$ | $Treat$ | -0.2736* | 0.0612 | -0.0327 | 0.0784 |
| $\rho_3$ | $Damage$ | -0.1309** | 0.0570 | -0.0923 | 0.0718 |
| $\rho_4$ | $t$ | 0.5689* | 0.0399 | 0.9867* | 0.0715 |
| **Variance parameters** | | | | | |
| $\sigma_u$ | | 0.1777* | | 0.1971* | |
| $\sigma_v$ | | 0.0224* | | 0.0687* | |
| | $\gamma = \sigma_u{}^2/(\sigma_v{}^2 + \sigma_u{}^2)$ | 0.9844 | | 0.8915 | |
| **Log-Likelihood** | | 4537.431 | | 1690.1367 | |
| **Wald-Chi square test (36)** | | 699547.390* | | 62141.92* | |
| **No of observations** | | | **2396** | | |

***,**,*** Significant levels at 0.01, 0.05 and 0.1, respectively.**

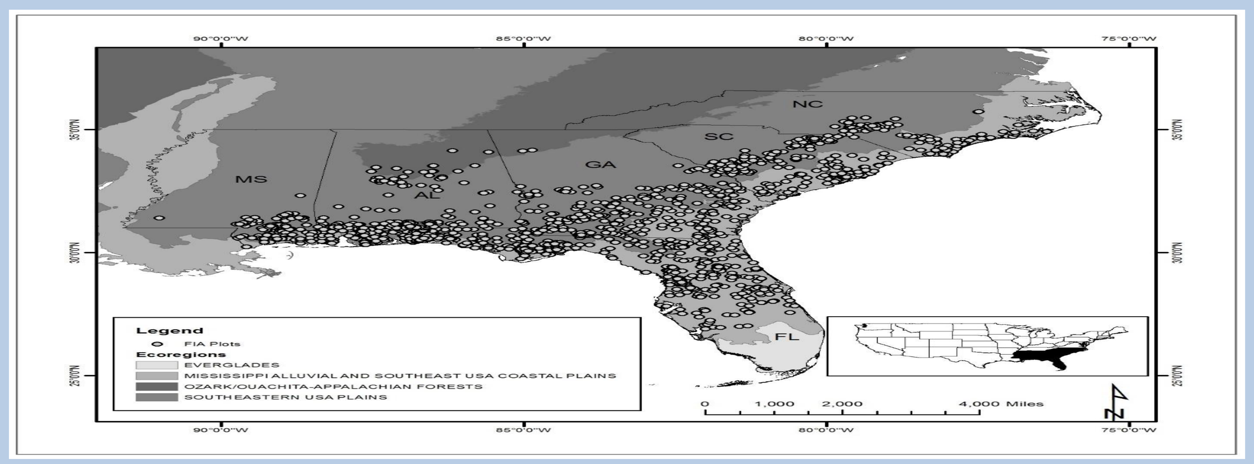


Fig. 1. Location of Forest plots