# *Resource Allocation of Ecosystem Services of Cross Timbers Forests*

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## Introduction

Forested ecosystems offer numerous goods and services, many of which are challenging to quantify directly. The productive potential of the Cross-Timber Forest region requires significant policy attention resulting from the economic contributions these services offer the locality – extending from southern Kansas to central Oklahoma and into Texas, including the metropolitan areas like Tulsa (Oklahoma), Oklahoma City (Oklahoma), and Dallas (Texas), providing ecosystem services to millions of residents along the Midwest-South continuum. Stand variety, in this transitional ecoregion, is largely comprised of post oak (Quercus stellata) and blackjack oak (Quercus marilandica) woodlands with varying tree densities interspersed with patches of tallgrass prairie with a a sizable portion of the region is not being actively managed, putting natural resources at risk of degradation (Susaeta, Sancewich, et. al. 2024). Active forest management tools, including prescribed burning, periodic thinning, and herbicides, have the potential to improve the production of ecosystem services and achieve socially desirable levels of associated public goods.

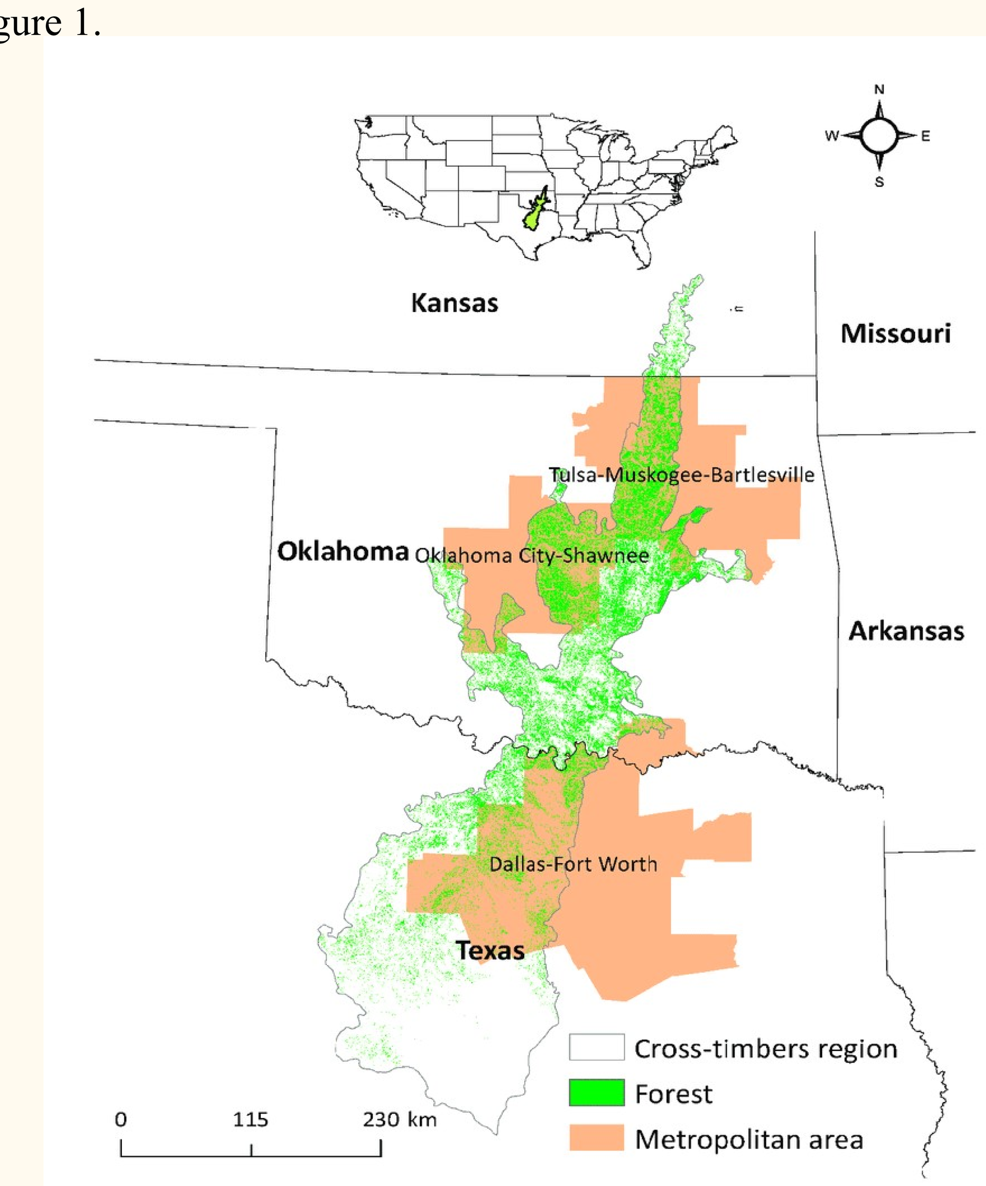
In addition, growth – economics and population – increase greenhouse gas emissions – these anthropogenic greenhouse emissions will cause the Earth's warming, increasing the global mean surface temperature between 1.1 °C and 4.8 °C by the end of the 21st century relative to 1986–2005 (IPCC, 2014). Changes in weather conditions are expected to have important impacts on natural systems with warmer temperatures may decrease water availability for streamflow and groundwater recharge, increase losses in species extinction, and shift the geographical distribution of forest plantations affecting timber supply in the region. However, the productivity of forestlands may be benefited with higher concentrations of carbon dioxide as long as water availability does not become a limiting factor (Susaeta, Sancewich, et. al. 2019); increased frequencies of natural disturbances associated with changes in weather conditions – such as fires, hurricanes and pest outbreaks – are expected to negatively affect the sustainability of forest.

Forestry is a joint production process where the production of and resources to ecosystems services are interlinked. An increase in planting to increase carbon sequestration and generate more pulpwood occurs at the expense of reducing the availability of water for streamflow. Thus, it is imperative to analyze the impacts of different forest management approaches coupled with changing weather conditions on the sustainable flow of ecosystem services to the input allocation to produce these services (Susaeta, Sancewich, 2019). Understanding the efficiency of input use on production provides insight into the performance the production process and the effectiveness of management practices.

We aim to expand the knowledge about efficiency in the provision of forest ecosystems in the Cross-Timber region of the United States (see figure 1) to understand the effectiveness of inputs allocation in the production process. We use an alternative parametric approach to estimate the efficiency in the production of forest ecosystem services known as stochastic frontier analysis (SFA) in this region. The input-oriented approach to technical efficiency represents the minimum input required to produce a given output. Stochastic frontier analysis, from an input perspective, determines the minimum amount by which a joint-production of inputs can be allocated to achieve the maximum output vector - are inputs overused in maximum output production? Measuring efficiency from an input-oriented perspective under the SFA approach allows one to: i) assessment the efficiency of forest management practices; ii) determine atmospheric impact on soil moisture in the provision of ecosystem services; iii) control for the random nature of biological growth, weather variability, natural disturbance impact, land ownership practices, and other climatic variables effecting soil moisture. Furthermore, the application of SFA – input orientated – in the scientific literature is related to the production of forest ecosystem services is scarce.

## Geographic Region

Figure 1.




## Objectives and Data

**Objectives:**

- Estimate the production efficiency of CT forests from an input allocation perspective.
- Determine the maximum level of joint production of timber, carbon sequestration, biodiversity, and water production while considering a set of forest inputs and other exogenous factors.
- Examine the impacts of forest management practices, stand attributes, natural disturbances, and climatic variables on the efficiency of input usage in output production.

**Data:**

- Using data from the USDA Forest Inventory and Analysis (FIA) program at the forest plot level
- Observations: 1448
- Locations: Kansas, Texas, Oklahoma
- Species: Softwoods (e.g., longleaf and shortleaf pines); Hardwoods (e.g., subcategories: hardwoods-1 (*hw1*: white oaks, red oaks) and hardwoods-2 (*hw2*: hickory, ash, eastern soft hardwoods, eastern hard hardwoods, and woodland hardwoods.

## Methodology

**The Stochastic frontier analysis (SFA)**

This model analyzes inefficiency in the production frontier under an input minimizing behavior of producers. This approach requires frontier estimates to first be obtained using an output-oriented approach. Once the output-frontier is obtained; input inefficiencies are calculated from the residuals in the frontier estimates. In addition, the output and input variables other environmental and control variables are included to capture heterogeneity in production, and factors that account for variations in the production efficiency (i.e., deviations in the efficient frontier). The production frontier is specified as follows:

$$Y_{it} = f(w_{it}, p_{it}, y_{it}, C_{it}, X_{it}; \alpha, \beta, \gamma, \delta) + v_{it} - u_{it}$$

$$u_{it} = \rho\tau_{it} + \varphi_{it}$$

where $Y_{it}$ represents the production for observation i*th* at time *t*, $w_{it}$ is the price of inputs, $p_{it}$ is the price of output, $y_{it}$ is the quantity of outputs, $C_{it}$ are control variables, and $X_{it}$ are environmental factors for the i*th* unit at time *t*. The model includes $v_{it}$, which is an independent and identically distributed (*iid*) normal random variable with mean 0 and variance $\sigma_v^2$ that captures random shocks. Additionally, $u_{it}$ is a non-negative random variable that measures inefficiency and is assumed to be *iid*, truncated at zero, and follows a half-normal distribution with variance $\sigma_u^2$. The compound term $v_{it}$ and $u_{it}$ allows for observations to deviate from the optimal profit frontier through inefficiency and random fluctuations.

Technical inefficiency viewed in terms of input-oriented (IO) production versus an output-oriented (OO) can be simplified as follows:

- Single y; single x; linear relationship (ln y; ln x).
- OO: vertical distance from a point below the efficient production frontier (an inefficient point), *u*
- IO: horizontal distance (IO inefficiency, *n*) times the slope *B,*
- *u = nB;* generalized form: *u = n∑ B*

*Variables:*

*Outputs:*

- Timber (e.g., sawtimber (*saw*) and pulpwood (*pulp*) ($m^3$ $ha^{-1}$)
- Carbon Sequestration ton $ha^{-1}$ $year^{-1}$;
- Water Yield ton $ha^{-1}$

Inputs:

- Species Richness (e.g., natural capital: number of tree species)

Environmental and Control Variables:

- Site Productivity
- Climatic variables (e.g., Temperature *(min, max);* Precipitation)
- Stand Age,
- Forest Disturbances
- Geographical Location
- Stand Ownership
- Forest Species

Inefficiency:

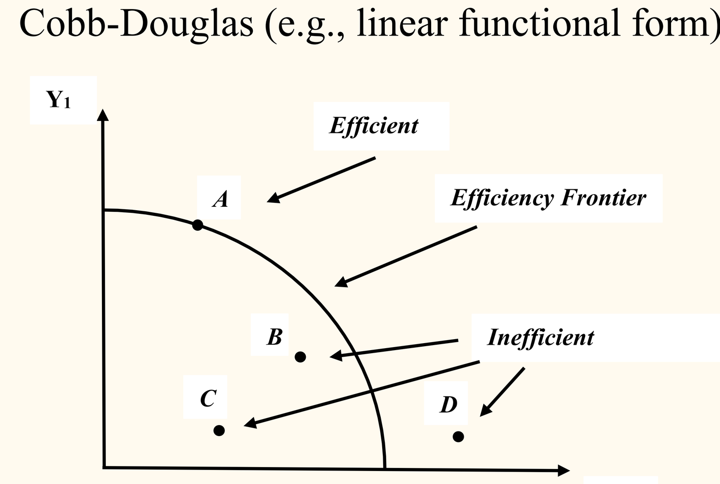
- Site Productivity
- Biological Damage (e.g., animal; insect; human)
- Environmental Damage (e.g., fire; weather; disease)

Other:

- Conditionality: Soil Moisture vs Atmospheric Temperature

Model Specification:

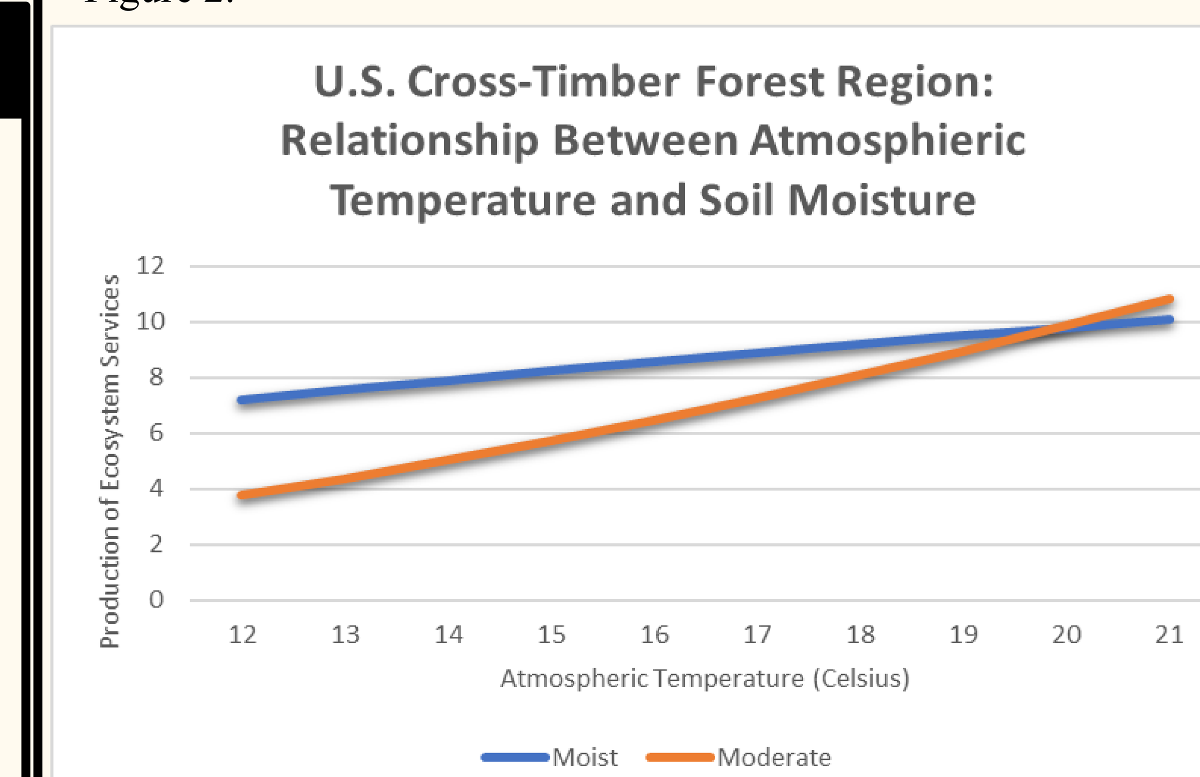
- Cobb-Douglas (e.g., linear functional form)




## Conclusions

To assess the production efficiency of the region's forests from an input-oriented perspective stochastic frontier analysis was applied. Frontier estimates were obtained from an output-oriented approach then input-oriented inefficiencies were calculated from the residuals of the frontier estimates. Using data from the USDA Forest Inventory and Analysis program at the forest plot level between 2004-2019, we examined the impacts of forest management practices, natural disturbances, and climatic variables on profit efficiency. Our results indicate that on average, 15.9 percent more input is used due to technical inefficiency with the production of ecosystem services increasing with atmospheric temperature. Noting a leveling off with soils with greater moisture with temperatures approximately 18-22 degrees Celsius indicating a decrease in productivity gains when soil is over saturated and nutrient uptake is slow. Moderate soil types show increasing productivity benefits with increases in temperatures indicating more efficient production of ecosystem services and nutrients are more evenly distributed within the production region. Though higher moisture content is shows the great initial production for lower temperatures (temp < 18 degrees Celsius). Inputs are less efficient when temperatures are lower for moderate soil moisture relative to those with greater moisture content. See figure 2.

Figure 2.




References:

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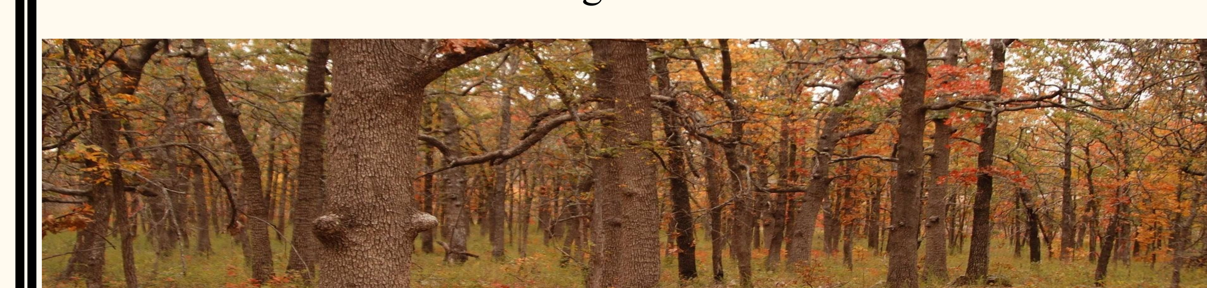

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