**Optimal Cellulosic Ethanol Plant Size under Uncertainty**

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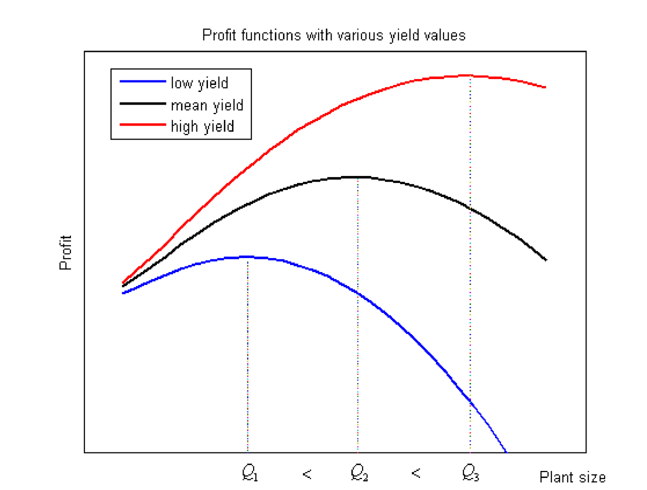
## Research question

Most study analyzes the optimal cellulosic ethanol plant size in a deterministic setting. The sensitivity of the optimal plant size to changes in key factors such as biomass density is often discussed. However, no work has been done to analyze optimal plant size when facing a stochastic world. The research question is: Comparing to the optimal plant size under certainty, will the optimal plant size under uncertainty be bigger, smaller, unchanged or uncertain?

## Assumptions and results find by previous researches

- The biomass considered is corn stover.
- The uncertainty comes from corn stover yield.
- Mean values of yields and prices' distributions are equal to the values under certainty.
- Yield has an impact on the capture region for biomass. High yield leads to a smaller capture region resulting in lower transportation cost. Low yield may lead a bigger capture region resulting in a higher transportation cost.



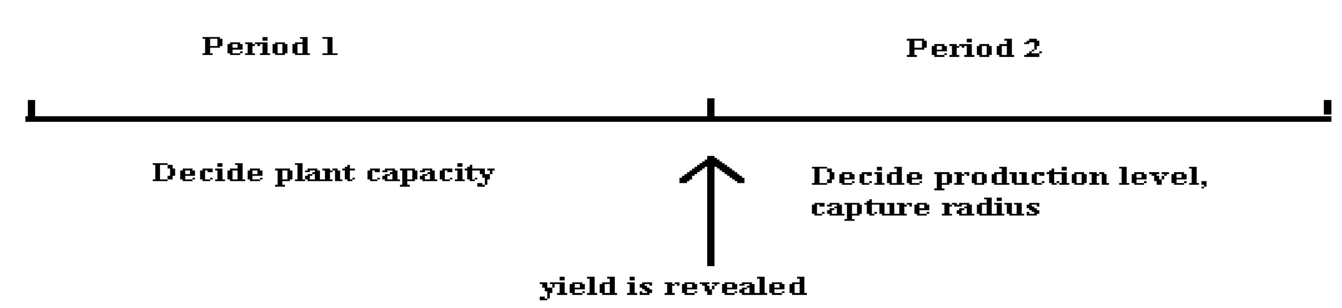

The profit functions as plant size for various yields are shown by graph on the left. Plant size with different yields under deterministic setting is found to be optimized at the maximum profit point. In deterministic settings, the findings are when yield is low optimal plant size decreases as shown by the blue line. When yield is high, profit increases and the optimal plant size is the biggest.

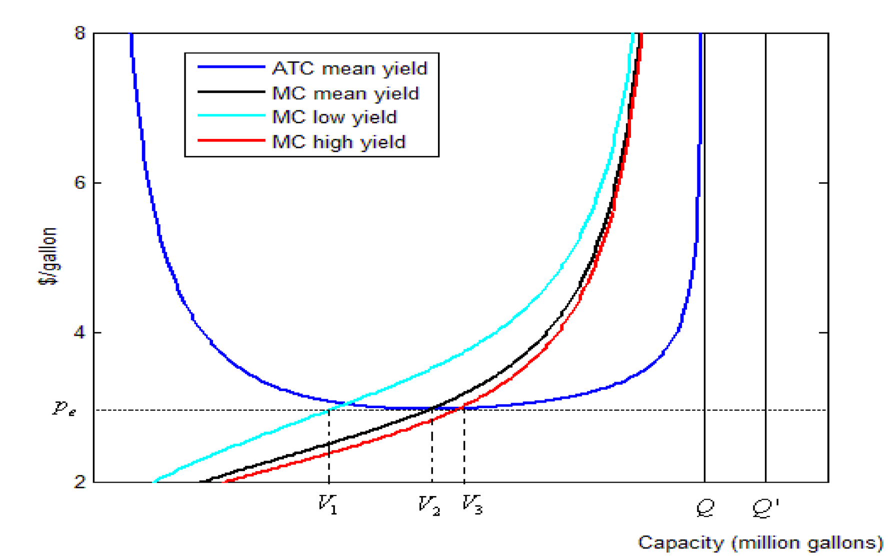
## Effect of risk on decision making for optimal plant size

- From Rothchild and Stiglitz (1971), we have the following condition for determining the economic effects of increasing risk.
- Profit ($\Pi$) under certainty is a function of plant size ($Q$) and yield ($y$). $\Pi_Q$ is the Marginal profit of plant size. With mean preserving spread in $y$, plant size under uncertainty comparing to that under certainty
- increases if $\frac{\partial^2 \Pi_Q}{\partial y^2} > 0$.
- unchanged if $\frac{\partial^2 \Pi_Q}{\partial y^2} = 0$.
- decreases if $\frac{\partial^2 \Pi_Q}{\partial y^2} < 0$.

## Method

- A simple mathematical model is used to model logistic costs and production cost for a plant located in the center of a circular region with uniformly distributed corn stover to find the profit function form ($\Pi$) under certainty.
- Pure math tells that the sign of $\frac{\partial^2 \Pi_Q}{\partial y^2}$ is uncertain. simulations are used to examine the conditions under which plant size increases or decreases with uncertain yield.
- In the simulation, we maximize the cellulosic ethanol plant's profits to determine optimal plant size under certainty.
- A two period model is used to simulate the plant size under uncertainty.
- Considering a plant is built before knowing the exact yield values in period one. The plant decides production level and stover capture radius in period two once stover yield is revealed. The timeline for decision making is shown below



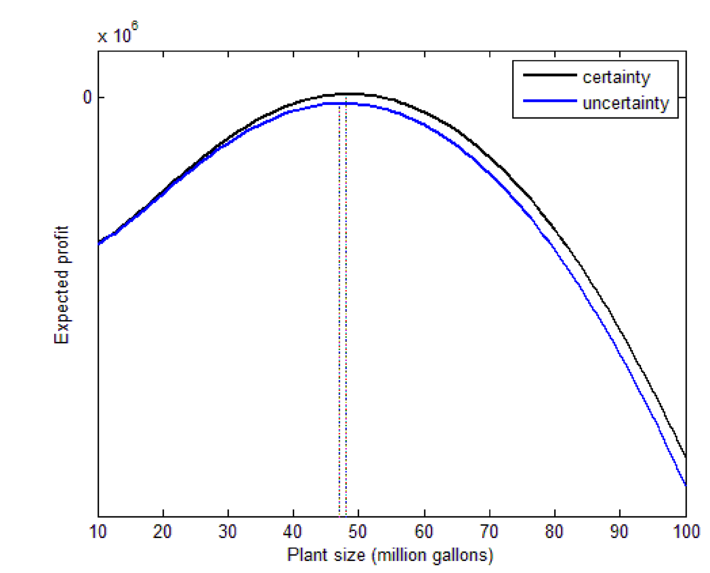

Problem is solve backwardly. The above graph shows how production decision is made under yield uncertainty in the second period.

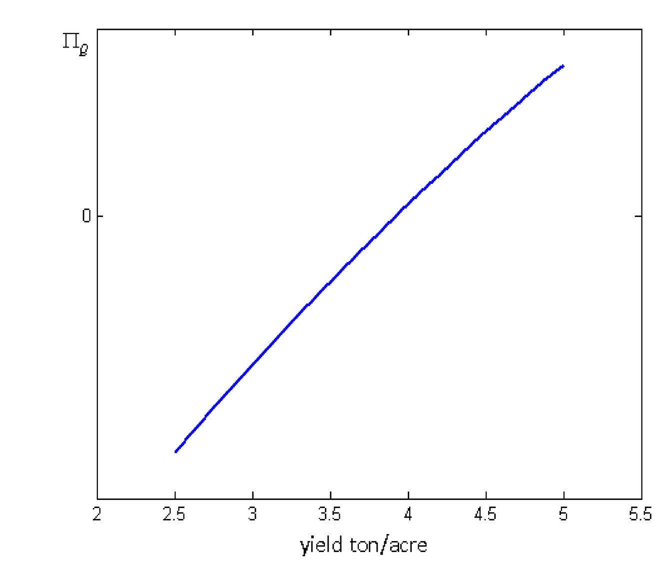
- Suppose $Q$ is the optimal plant size under certainty. Cellulosic ethanol price is chosen to make the model breakeven under certainty. Thus price ($p_e$) equals to the minimum average total cost (ATC) at $Q$.
- Under each capacity ($Q$, $Q'$,…) , The optimal production level in the second period is determined by letting price equal to the marginal cost (MC) given different yields. For low yield, production level is $V_1$. The production level increases to $V_3$ when yield is high.
- Then we get the expected profit for each capacity and the optimal plant size under uncertainty the one that maximize expected profit.

## Results

The left graph below shows how increasing risk cause a difference in optimal plant size in a baseline simulation. The black line is the profit function of plant size under certainty. The black line is the expected profit function of plant size under uncertainty.

- Plant size under uncertainty is only 1millin gallon per year less than the plant size under certainty. Plant size is almost unchanged with mean preserving spread in yield.
- Sensitivity analysis (different transportation cost, production cost factors) confirms that optimal plant size is almost the same under uncertainty.
- The simulation results implies that the marginal profit of plant size ($\Pi_Q$) is almost linear in yield in the range of possible yield values as shown by the graph below on the right (Rothchild and Stiglitz).




## References

Rothchild, M. and J. E. Stiglitz (1971). Increasing Risk II: Its Economic Consequences. Journal of Economic Consequences. Journal of Economic Theory 3(1), 66-84.