Modeling Cropland Allocation in the U.S. from 1997 to 2010: Theory and Empirical Estimation

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Introduction

As the primary input to food production, allocation of cropland is an important factor in determining the supply of food. Modeling cropland change is vital in understanding how land is allocated among crops and predicting future land allocation patterns when economic conditions change. The key parameter for cropland allocation process is the elasticity of land use with respect to expected net returns. It reflects the speed and magnitude of land supply adjustments in response to changes in product price or cost. The literature on cropland allocation can be categorized into two types. One utilizes econometrics to estimate a hypothesized statistical relationship between various economic variables and cropland supply for one or a few crops. The other type employs economic modeling where the total cropland supply is accounted using a convex function with assumed parameters. In this paper, we will include major crops in a coherent system and directly estimate the Constant Elasticity of Transformation function that governs the land allocation.

Methodology

We model cropland allocation as an annual decision. The changes in cropland allocation across crops are motivated by farmers' net revenue maximizing choices subject to a land constraint while taking into account the conversion cost.

To build a more flexible structure for cropland allocation, the paper proposes a multi-level nested CET function $f(L_1,...,L_n)$ to handle the cropland allocation. There is a single elasticity of transformation associated with each nest, so that the structure has the ability to distinguish the ease of land transformation among crops within different nests. The problem is reformulated as:

Max: $\sum_{i=1}^{n} NR_i L_i - C(TPL)$

s.t.: $f(L_1,...,L_n) \le TPL : \pi$

TPL: Total available productivity adjusted; *C*(*TPL*) is the increasing concave conversion cost function; NR_i : per unit of land net revenue generated to grow crop *I*; L_i: the amount of land allocated to crop *i*; *n* represents total number of crop types; π represents the shadow value of cropland.

The Lagrangian for this optimization problem at time t is:

$$L_t = \sum_{i=1}^{n} NR_{it} L_{it} - C(TPL_t) - \pi_t [f(L_{1t},...,L_{nt}) - TPL_t]$$

Assuming an interior solution, first order optimality conditions for this problem are:

$$\frac{\partial \mathcal{L}_t}{\partial L_{it}} = NR_{it} - \pi_t \frac{\partial f(L_{1t}, \dots, L_{nt})}{\partial L_{it}} = 0 \qquad \forall i = 1,2,...,n; t = 1,2,...,T$$

$$\frac{\partial \mathcal{L}_t}{\partial \mathrm{TPL}_t} = \frac{\partial C(TPL_t)}{\partial TPL_t} \cdot \frac{\partial TPL_t}{\partial L_{it}} + \pi_t = 0 \qquad \forall t = 1,2,...,T$$

$$\frac{\partial \mathcal{L}_t}{\partial \pi_t} = f(L_{1t}, \dots, L_{nt}) - \mathrm{TPL}_t = 0 \qquad \forall t = 1,2,...,T$$

Estimation

Only the first order condition is observable from which the parameters can be estimated. To eliminate the need for estimating the time-varying parameters , the estimation equations are expressed as ratios of first order conditions with one equation taken as the divisor. By using each of the crops as the divisor in turn and stacking the resulting equations, we obtain a system whose estimates are invariant to choice of divisor. With *n* crops generating *n* first order conditions, each ratio system contains (*n* – 1) equations, and with *n* potential divisors, the resulting system contains equations. Thus, when equation *i* is chosen as the divisor,

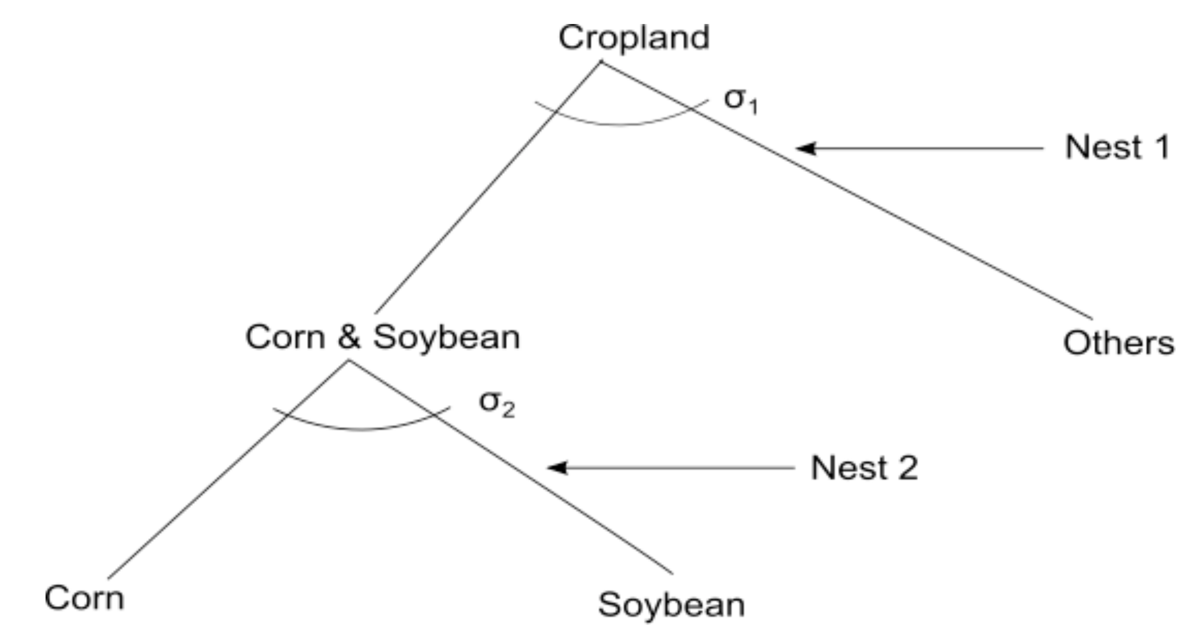
$$\frac{NR_{jt}}{NR_{it}} = \frac{\pi_t \dfrac{\partial f(L_{1t},...,L_{nt}|\underline{\beta})}{\partial L_{jt}}}{\pi_t \dfrac{\partial f(L_{1t},...,L_{nt}|\underline{\beta})}{\partial L_{it}}} = \frac{\dfrac{\partial f(L_{1t},...,L_{nt}|\underline{\beta})}{\partial L_{jt}}}{\dfrac{\partial f(L_{1t},...,L_{nt}|\underline{\beta})}{\partial L_{it}}} \qquad \varepsilon_{jit} = \frac{NR_{jt}}{NR_{it}} - \frac{\dfrac{\partial f(L_{1t},...,L_{nt}|\underline{\beta})}{\partial L_{jt}}}{\dfrac{\partial f(L_{1t},...,L_{nt}|\underline{\beta})}{\partial L_{it}}}$$

$t = 1,...,T \; i, j = 1,...,n \; i \ne j$.

Errors are assumed to be multi-normally distributed as $N(0, \Sigma)$.

Data

- Corn and Soybeans are primary focus with an additional category for other crops

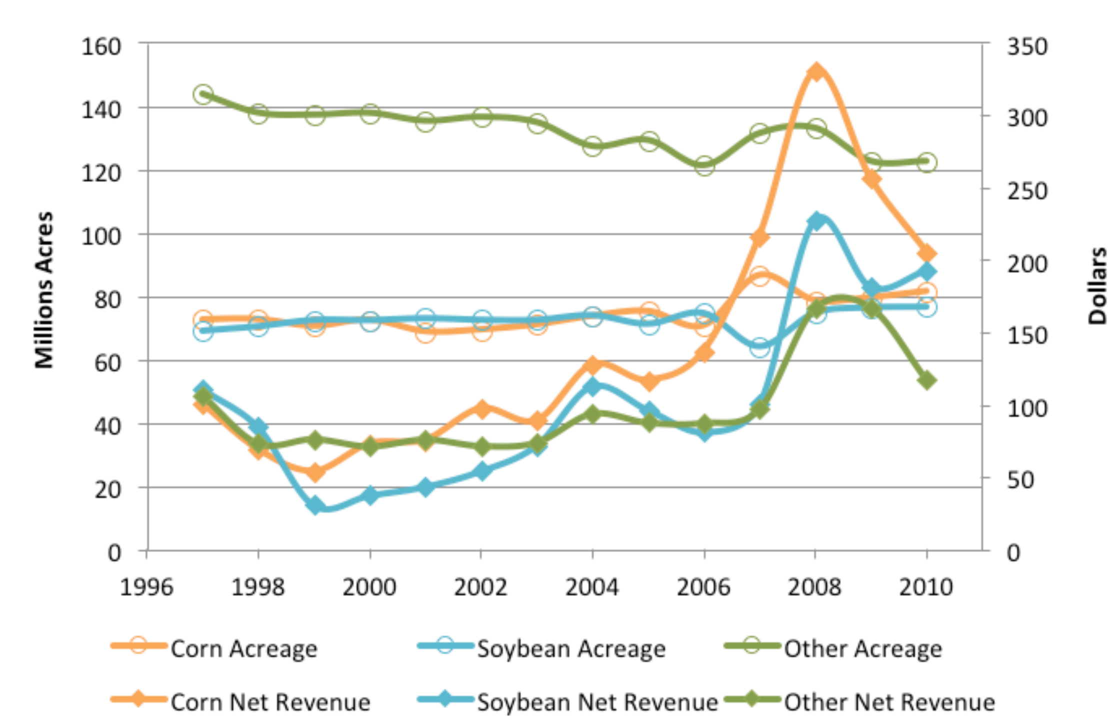


- Price, yield, harvested acres and government subsidies are from USDA-NASS
- Production cost is obtained from ERS

Descriptive Statistics of Collected Data

Variable	Unit	Description	Mean	Std Dev	Min	Max
nr_corn	$	Net revenue per acre for corn	164.63	117.06	54	457.22
nr_soy	$	Net revenue per acre for soybean	113.76	76.11	30.82	275.54
nr_others	$	Net revenue per acre for others	101.39	36.03	71.57	167.46
acre_corn	mil. acres	Harvested acres for corn	74.47	5.19	68.77	86.52
acre_soy	mil. acres	Harvested acres for soybean	72.43	3.17	64.15	76.62
acre_others	mil. acres	Harvested acres for others	132.25	6.77	121.32	143.84

Harvested Acres and Net Revenue for Corn, Soybean and Others



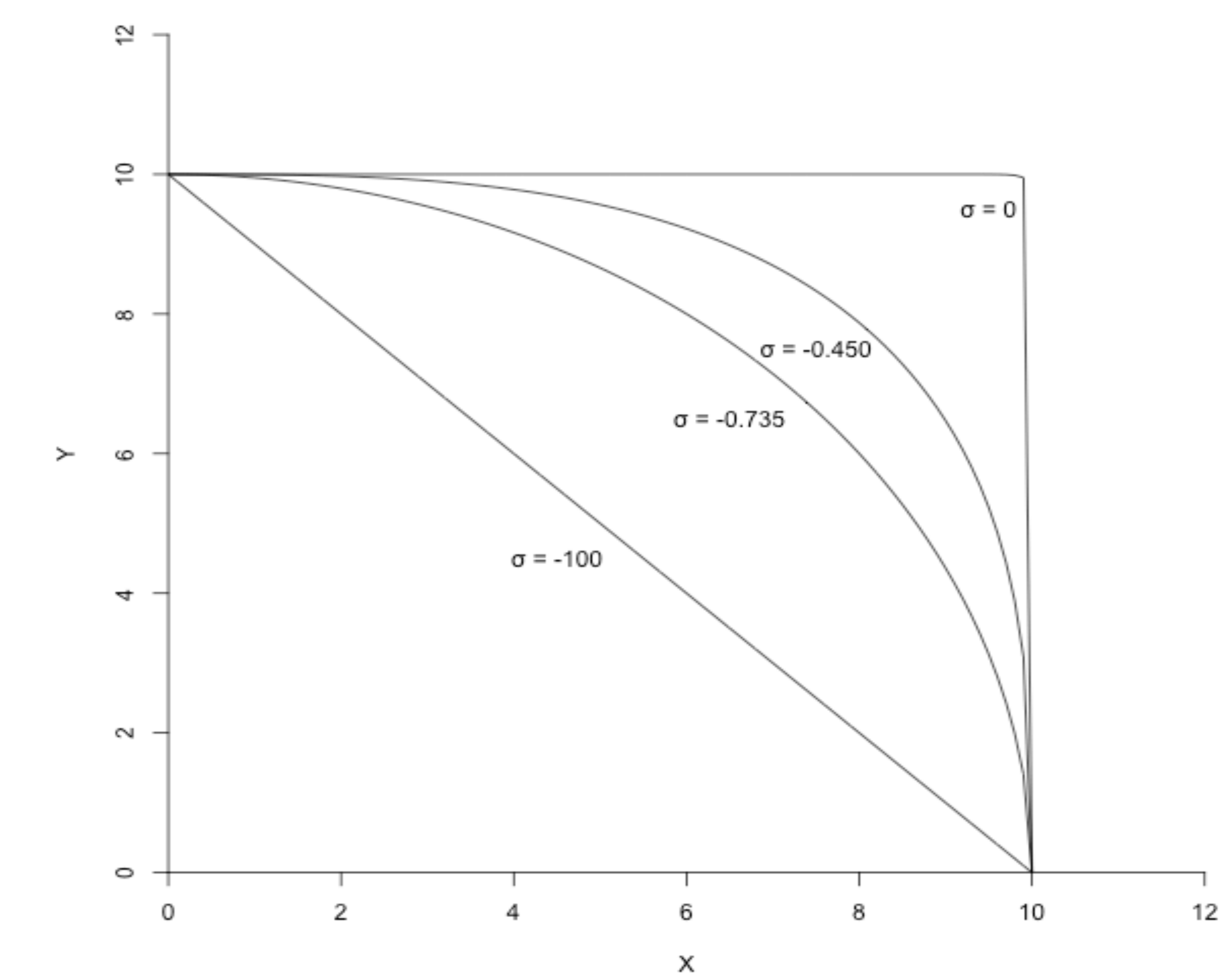
Results

Parameter Estimates from Seemingly Unrelated Regression

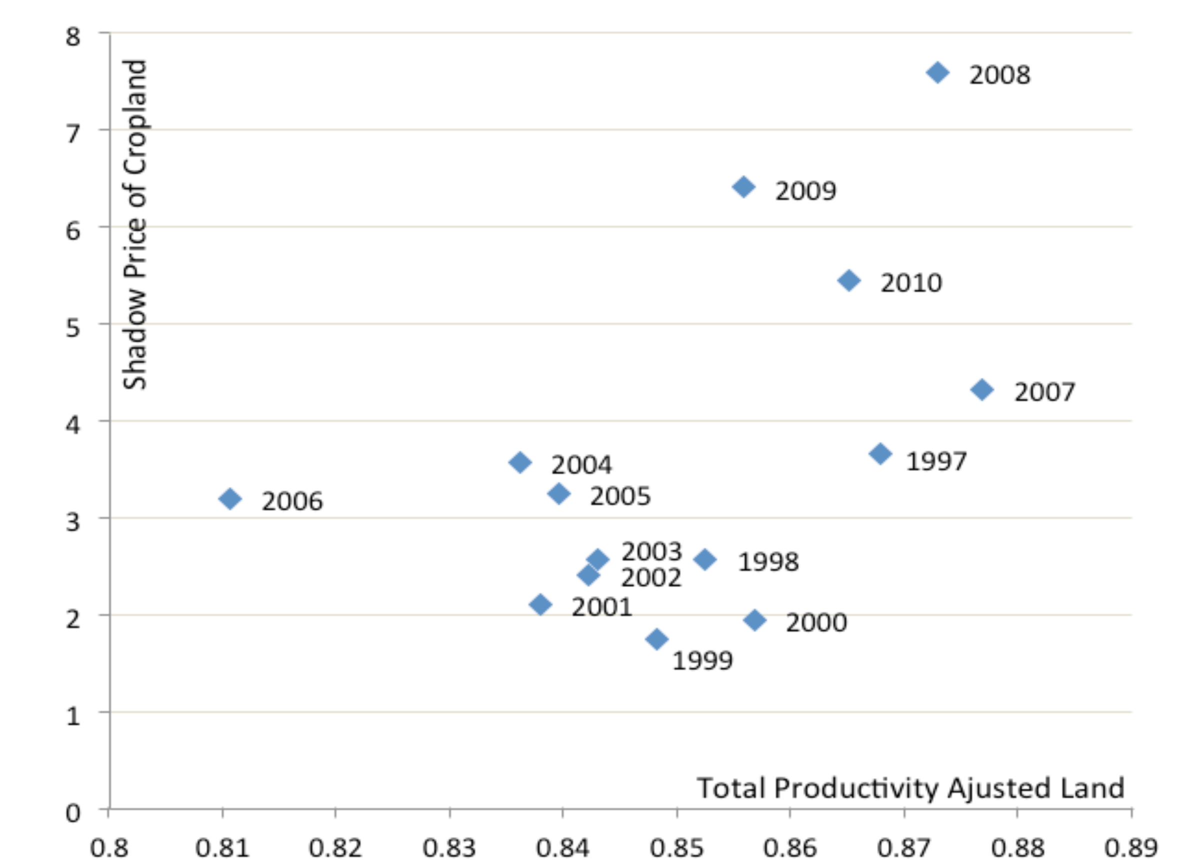
Parameter	Description	Estimate	Calculated Std. Error	t Value	Elasticity of Transformation $\sigma = 1/(1-\rho)$
λ_1	Share parameter of corn and soybean composite in nest 1	0.897***	0.014	62.290	-
λ_2	Share parameter of corn in nest 2	0.580***	0.008	71.880	-
ρ_1	CET parameter at nest 1	3.224***	0.247	13.080	-0.450
ρ_2	CET parameter at nest 2	2.360***	0.141	16.710	-0.735

Results_cont.

Transformation Frontiers with Different Constant Elasticity of Transformation



Shadow Price of Cropland Constraint vs. Total Productivity Adjusted Land



Conclusion

- Despite the small number of observations, we find some evidence in support of the nested structure as opposed to a single level CET.
- The work here may be useful for econometrically measuring the substitution possibilities among different crops.
- We can also further apply this model at a subnational level.