The Impact of Climate Variability on the Production Efficiency and Incomes of Kansas Farms

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Introduction:

Agriculture in the United States is highly dependent on climate. Climate change and variability are significant forces that influence farm operations and management decisions, and ultimately rural livelihoods. Consequently, there is a need for increased understanding of the economic impact of climate change and climate variability at the farm sector level.

Most economic analyses of climate change impacts and mitigation have focused on aggregate costs and benefits (Hertel, 2010). Empirical analyses of the impact of climate change and climate variability on the production efficiency and incomes at the farm level are still rare.

Objective:

The purpose of this study is:

- To investigate the impact of climate variability on the production efficiency of farms in Kansas. The effects of temperature and precipitation are modeled under different stochastic production frontier specifications.
- To investigate the impact of climate variability on total farm income, crop income and livestock income using a fixed effects panel regression model.

Methods

1. Theoretical Stochastic Production Frontier Model

$$y_{it} = f\left(X_{it}, t; \beta\right)\exp\{v_{it}\}\exp\{-u_{it}\}$$

$$u_{it} = \alpha + \delta Z_{it} + \varepsilon_{it}$$

Note: Our approach assume that climate variability affects the technical efficiency of farms, and therefore, farm incomes. Farmers are able to adapt in response to change in climate variability by, for example, altering planting dates, changing crop mix or fertilizer use. Technical efficiency and farm income also vary by farm size and specialization.

2. Empirical Stochastic Production Frontier Model

$$\ln y = \ln f\left(\boldsymbol{x}, \boldsymbol{\beta}\right) = \beta_0 + \sum_{i=1}^{n}\beta_i \ln x_i + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n}\beta_{ij}\ln x_i \ln x_j, \text{with } \beta_{ij} = \beta_{ji}$$

$$u_{it} = \alpha + \beta_{it}^T x_{it} + \theta_i^T f_i\left(w_{it}\right) + \varepsilon_{it}$$

Note: The dependent variable is value of farm products, X_i are inputs (capital, labor, purchased inputs. Time and precipitation also enters the model multiplicatively. The inefficiency model includes climate variables (W_{it}) and variables that determine technical efficiency (X_{it}).

3. Fixed Effect Model

$$y_{it} = \alpha_i + \gamma_i + X_{it}'\beta + \sum_i \theta_i f_i\left(w_{ict}\right) + u_{it}$$

Note: The dependent variable is farm revenue, α_i is the farm full effects, λ_i is time effects, X_{it} is a vector of observed determinants of farm income that are time varying, Wit are annual climate variables that vary by season and U_{it} is the error

Data Sources

- Output and inputs: 1 output (value of farm production) and 3 inputs (capital, labour and purchased inputs) for 583 farms for the period 1993 to 2005. All variables are measured in real dollar values with year 2005 as the base year. This data comes from the Kansas Farm Management Association database.
- Climate variables: annual temperature and precipitation for 4 seasons (Summer, Autumn, Winter and Spring. This data is obtained from the National Oceanic and Atmospheric Administration (NOAA) website.

Empirical Results: Stochastic Frontier Model

Table 1. Estimated Stochastic Frontier Models

	Error Components Frontier		Efficiency Effects Frontier	
	Model 1	Model 2	Model 3	Model 4
a_Cons	-1.285	-4.986***	-6.492***	-6.319***
a_K	0.619**	0.750**	0.573**	0.556**
a_L	-0.030	-0.106	0.041	0.064
a_P	0.788***	0.716***	0.852***	0.851***
a_R	-0.018	0.213***	0.325***	0.319***
a_T		0.039	0.029	0.030
b_K_K	0.127***	0.120***	0.092***	0.096***
b_K_L	0.019	0.023	0.044*	0.044*
b_K_P	-0.141***	-0.142***	-0.106***	-0.109***
b_K_R	-0.006**	-0.002	0.000	0.000
b_K_T		-0.007***	-0.007**	-0.007**
b_L_L	-0.026	-0.030	-0.027	-0.026
b_L_P	-0.005	-0.004	-0.037*	-0.039*
b_L_R	0.002	0.000	0.001	0.001
b_L_T		0.003	0.000	0.000
b_P_P	0.114***	0.116***	0.077***	0.081***
b_P_R	0.006***	0.002	0.000	0.000
b_P_T		0.007***	0.011***	0.010***
b_R_R	0.003***	-0.007***	-0.010***	-0.010***
b_R_T		-0.003***	-0.004***	-0.004***
b_T_T		0.006***	0.006***	0.007***
Z_t_win			0.552*	-0.504
Z_t_sp			0.949*	0.883
Z_t_sum			-1.302**	0.739
Z_t_fall			0.493**	-0.103
Z_p_win			5.021*	1.104
Z_p_sp			4.260*	-0.259
Z_p_sum			-11.106**	-0.566
Z_p_fall			3.871**	0.476
Z_t_p_win			-0.166*	-0.545**
Z_t_p_sp			-0.080*	-0.043*
Z_t_p_sum			0.148**	0.065**
Z_t_p_fall			-0.066**	-0.050**
Z_t2_win				0.047*
Z_t2_sp				-0.003
Z_t2_sum				-0.017*
Z_t2_fall				-0.001
Z_p2_win				2.858**
Z_p2_sp				0.081*
Z_p2_sum				-0.208
Z_p2_fall				0.125**
sigmaSq	0.101***	0.099***	0.220***	0.242***
gamma	0.547***	0.562***	0.846***	0.861***

Note: K is capital, L is labor, P is purchased inputs, R is mean precipitation T is time.

Dependent variable is value of farm products from crop and livestock

Climate variability variables are temperature (t) and precipitation (p) for Winter (win), Summer (sum), Spring (sp) and Fall (fall).

Model 1 and 2 are Error Component Models; Model 2 differs from Model 1 by inclusion of precipitation as an input.

Model 3 and 4 are Efficiency Effects Models. Model 4 differs from 3 by inclusion of quadratic terms of weather variables.

Likelihood ratio test rejects Model 1 for Model 2 and Model 4 for Model 3.

Empirical Results: Panel Data Model

Table 2. Fixed Effects Estimates of Climate Variability on Farm Incomes

Variable	Farm Income	Crop Income	Livestock Income
t_win	-.184***	-.112***	.378***
t_sp	-.234***	-.317***	.246***
t_sum	.227***	.035	-.915***
t_fall	.092***	.135***	-.428***
p_win	-1.718***	-1.218***	3.424***
p_sp	-1.289***	-2.055***	1.431**
p_sum	1.522***	0.226	-4.963***
p_fall	.610***	.7256***	-3.643***
t_p_win	.054***	.042***	-.104***
t_p_sp	.025***	.039***	-.027**
t_p_sum	-.020***	-0.003	.064***
t_p_fall	-.012***	-.014***	.067***
dvs	-1.372***	-1.171***	-1.564***
ds	-.824***	-.735***	-.908***
dm	-.384***	-.363***	-.359***
sliv	.116***		
smix	.044***		
_cons	8.780***	22.970***	80.800***
N	7579	7519	5853
R^2	.570	.334	.122
Adjusted R^2	.533	.277	.040

Note: t is temperature for the 4 seasons (winter, spring, summer and fall), p is precipitation for the four seasons. We control for farm size and specialization; dvs is very small farms, ds is small farms and dm is medium sized farms. sliv is livestock enterprises.
*Note: *, **, and *** denote, respectively, significant at 1%, 5% and 10%.*

Table 3. Farm Income Projections

	Temperature Change	% Change in Mean Revenue	% Change in Mean Revenue
Maximum	9	6.696	0.239
mean	8	5.135	0.294
temperature	7	3.890	0.349
increase	6	2.898	0.408
	5	2.107	0.470
	4	1.477	0.534
Base	0	0.000	0.000
	4	-0.521	
Minimum	5	-0.601	
mean	6	-0.668	
temperature	7	-0.724	
increase	8	-0.770	
	9	-0.809	

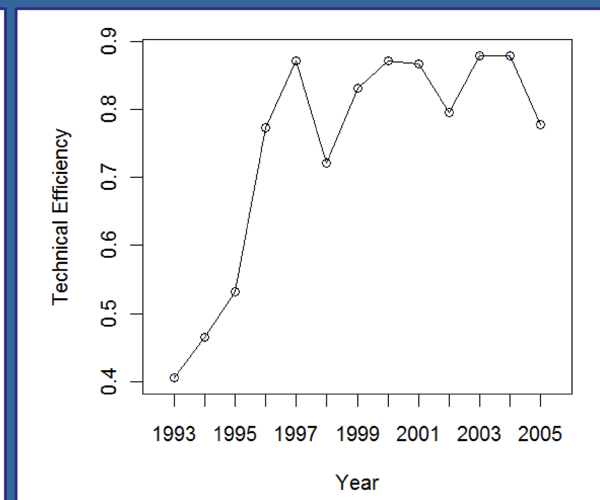
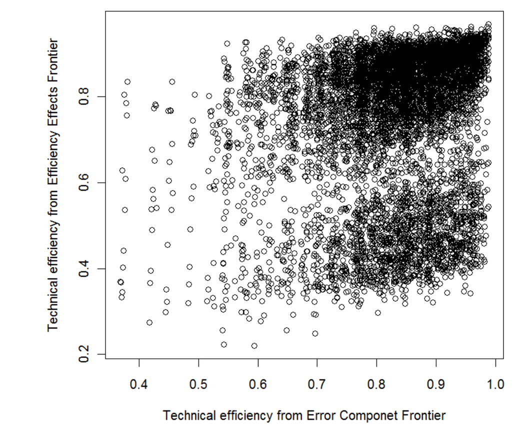


Figure 1. Technical Efficiency (Model 3)



Note: The unfilled circles represent technical efficiencies from the two models that do not match.

Figure 2. Scatterplot of Technical Efficiency Scores from the Efficiency Effects and Error Component Frontiers (Model 2 and 3)

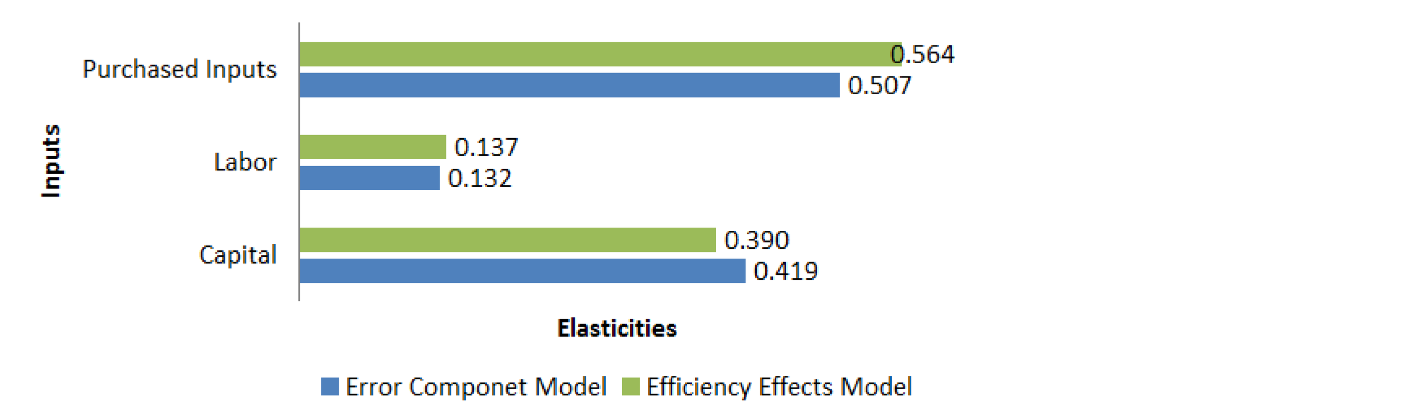
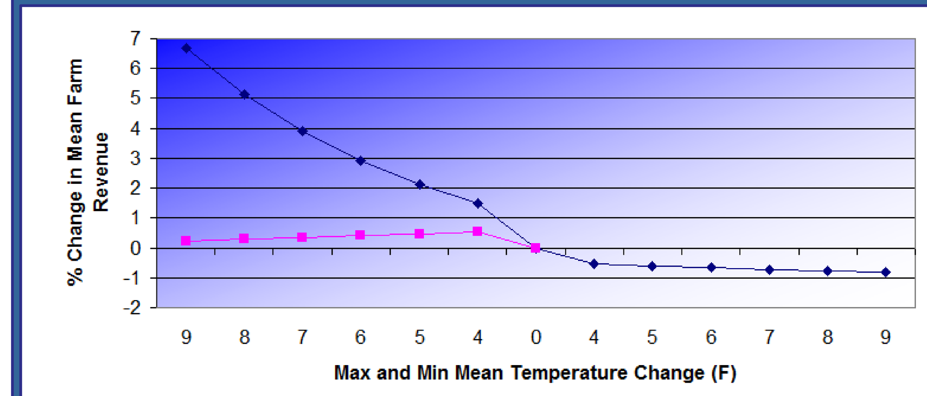


Figure 3. Partial input elasticities from the Efficiency Effects and Error Component Frontiers (Model 2 and 3)



Note: Temperature changes based on 30 years predictions of the Canadian and Hardely Climate Change models.

The red line shows the combined effects of increase in both maximum and minimum mean temperatures from the base scenario

Figure 4. Change in farm revenue (% from mean) of mixed enterprises due to changes in maximum and minimum mean temperatures

Summary & Conclusion:

Climate variability significantly affects mean output elasticities with respect to inputs, returns to scale, and technical efficiencies. Purchased inputs are more sensitive to climate variability than capital and labor.

Based on 30 years climate projections from the Canadian and Hardely climate change models, farm incomes will increase with a modest increase in mean maximum temperatures and decrease with a modest increase in mean minimum temperatures, *ceteris paribus*. The combined effects is a modest decline in average farm incomes within a range of 0.2 to 0.5 percent.

Overall impact of temperature variability on farm incomes will be quite modest in the medium term.

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