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The Ricardian Model of Climate Change Impact with Interregional Trade Flows : Evidence from the U.S. Agriculture

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Motivations

- Climate is changing and its variability is increasing (Dominguez et al., 2012);
- Open debate about the impact of climate change on U.S. agriculture;
  - Gains: Mendelsohn *et al.* (1994); Massetti and Mendelsohn (2011).
  - Losses: Schlenker *et al.* (2006, 2009); Deschênes and Greenstone (2012).
- US is the largest player in world food market + Numerous sectors rely on agriculture.

Three major approaches to evaluate the impact of climate change on agriculture:

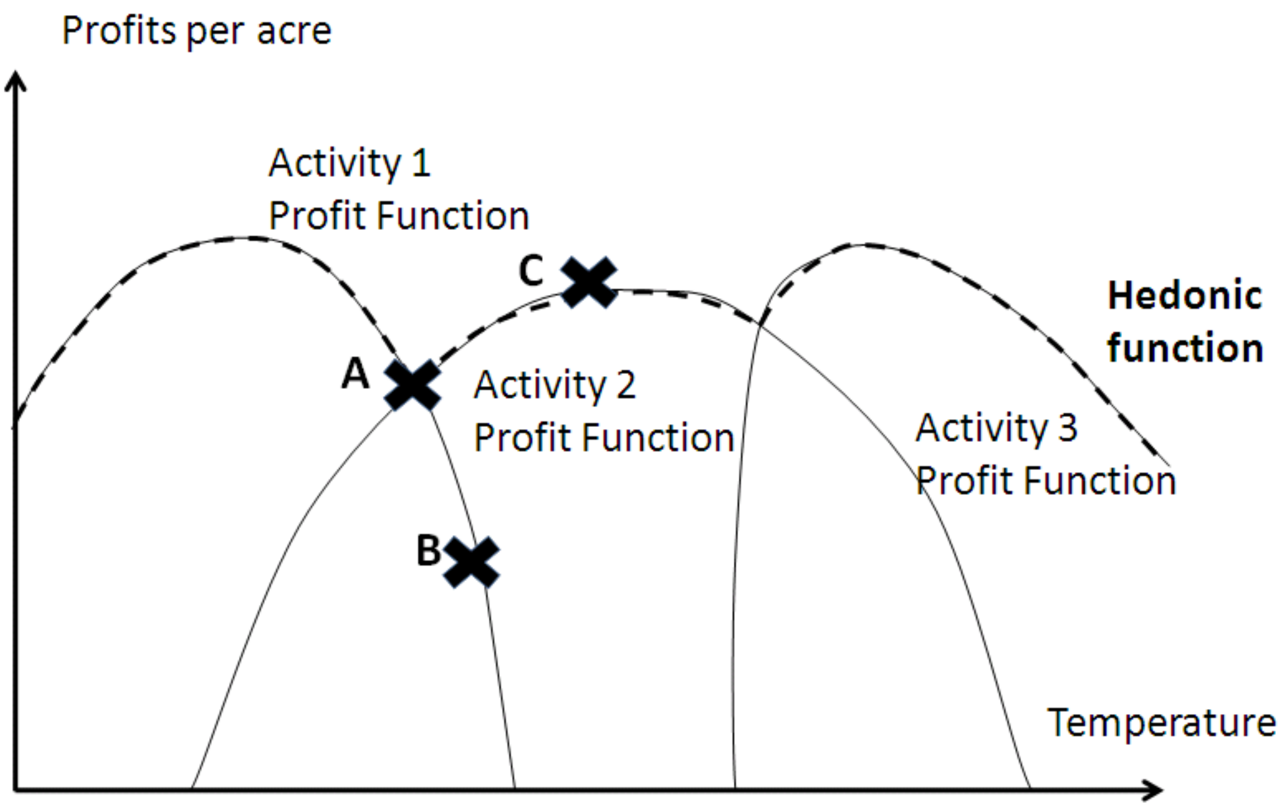
(1) crop growth simulation models (Nordhaus, 1991; Tol, 1995; Mendelsohn and Neumann, 1999; Nelson et al., 2009),

(2) crop production function models (McCarl et al., 2008; Lobell et al., 2008; Burke and Emerick, 2015; Schlenker and Roberts, 2009);

(3) Ricardian approach.

No presence of interstate trade in the current Ricardian literature on US agriculture

Basic Ricardian approach ("Clairvoyant farmer")



Basic Ricardian approach

$$\text{Land\_value}_i = X_i'\beta + \sum \theta_j f_j(T_{ij}) + \varepsilon_i \qquad \varepsilon_i \sim N(0, \sigma_\varepsilon^2)$$

$$\textbf{Land Val}_t = \sum_{k=0}^{\infty} \delta^k \mathbb{E}_t(NR_{t+k})$$

Where $\mathbb{E}_t(NR_{t+k}) = \max_a \mathbb{E}_t(NR_{t+k}^a)$

a = index of feasible activities

Can also be **agricultural profit**

Control variables: Soil conditions and Human Intervention

Climate variables: many functional forms e.g. quadrics average temp. and rainfall , degree-days, temp. bins.

Vast literature on US agriculture only:

[Dep. Var.: Farmland value]

Mendelsohn et al. (1994), Polsky (2004), Mendelsohn and Dinar (2003), Massetti and Mendelsohn (2011), Schlenker et al. (2005, 2006), Dall'erba & Dominguez (2015)

[Dep. Var.: Agricultural profit]

Kelly et al. (2005); Deschênes and Greenstone, (2007); Fisher et al. (2012)

Assumptions of the basic Ricardian approach

- **Competitive Land Market** Farmland value is equal to the discounted sum of future agricultural profit.
- **Smart Farmer Hypothesis** Changes in farmland value reflect the net impact of climate change after farmers adapt to it as well as they can.
    - **No Spatial Spillover Effect** between any two regions.

Origins of spatial dependence:

- Ezcuerra *et al*. (2008): ecological fallacy (weather and soil conditions)
- Cochrane (1979), Rogers (1995): personal network
- Berger (2001), Polsky (2004), Munshi (2004): professional network
- Dall'erba and Dominguez (2015): surface irrigation water, cycle of water, knowledge externalities
- **This contribution: interregional trade linkages** (HOS, 1953; Dixit and Stiglitz, 1977; Helpman and Krugman, 1985)

Spatial dependence in previous Ricardian works

- **No Spillovers:** i.i.d errors, Conley's standard errors, SER ($\partial y_i / \partial x_{i,r} = \beta_r \quad \partial y_j / \partial x_{i,r} = 0$)

- Mendelsohn et al. (1994), Schlenker *et al.* (2006), Deschênes and Greenstone (2007), Lippert *et al*. (2009).

- **Global Spillovers**: SAL or SDM ($\partial y / \partial x_r = (I_n - \rho W)^{-1} \beta_r = (I_n + \rho W + \cdots + \rho^n W^n)\, \beta_r$)

- Polsky (2004), Seo (2008), Chatzopoulos and Lippert (2016), Dall'Erba and Dominguez (2015).

- **Local Spillovers:** SLX ($\partial y / \partial x_r = \beta_r + W\theta_r$)

- Dall'Erba and Dominguez (2015).

- Problems:

(1) Weight matrix is commonly based on geographical proximity (symmetry, no directionality, no time change);

(2) Spatial model selected on statistical tests, not on economic theory (Corrado and Fingleton, 2011; Ertur and Koch, 2007; Llamosas-Rosas and Dall'erba, 2015).

The significant role of trade

- Trade as an adaptation mechanism to climate change (e.g., Reilly and Hohmann, 1993; Rosenzweig and Parry, 1994; Taigas *et al*., 1997; Randhir and Hertel, 2000; Julia and Duchin, 2007; Costinot *et al*., 2016).

  Comments: (1) mostly use CGE-based models; (2) focus on the international level.

- US 2012 domestic trade flows (Freight Analysis Framework Version 4);
- Isolate the trade flows of **cereal grains** and **fruits, vegetables, seeds** from the other flows: animals, fish, animal feed, prepared foodstuff, manufacturing products

		Min.	1st.Qu	Median	Mean	3rd.Qu	Max.
Export_ratio	$ER_i = 1 - \frac{T_{ii}}{\sum_j T_{ij}}$	0.2544	0.5189	**0.5189**	**0.5150**	0.5923	0.8894
		Min.	1st.Qu	Median	Mean	3rd.Qu	Max.
Import_ratio	$IR_i = 1 - \frac{T_{ii}}{\sum_j T_{ji}}$	0.1052	0.4273	**0.5379**	**0.5120**	0.6346	0.9592

	Top 3			Bottom 3		
Export_value	California	Illinois	Ohio	Wyoming	West Virginia	Delaware
Import_value	Illinois	Pennsylvania	Texas	Wyoming	Vermont	West Virginia

Two stage estimation procedure

- First stage --- Gravity model (OLS and PPML)
  - Use FAF4 domestic trade flow data as dependent variable in a standard gravity model;
  - Use the predicted trade flows to construct the trade weight matrices.
- Previous literature on gravity models applied to agricultural trade
  - Heerman *et al.* (2015), Sun and Reed (2010), Grant and Lambert (2008), Cho *et al.* (2002)
  - **Comments**: international trade data + focus on evaluating trade policies.

- Second stage --- Ricardian model (ML)
  - Add the spatial lag of intermediate demand;
  - The marginal effect of the covariates (including weather) is both local and trade partners based;

First stage -- Gravity model

$$w_{i_j n_k} = \beta_0 + \mathbf{D}'_{i_j n_k}\boldsymbol{\delta} + \mathbf{S}'_{i_j}\boldsymbol{\beta} + \mathbf{M}'_{n_k}\boldsymbol{\gamma} + \nu_j + \nu_k + \epsilon_{i_j n_k} \qquad \epsilon_{i_j n_k} \sim N(0, \sigma_\epsilon^2)$$

i = exporter index (48 states), n = importer index (48 states), j & k = indices for (9) climate-regions, sample size: 2,256 pairs

w_{in} = (log of) bilateral trade flow of crops, fruits, veggies from i to n [FAF 4 data]

$\mathbf{D}_{in}$ = bilateral accessibility of n to exporter i (continuity dummy, distance dummies)

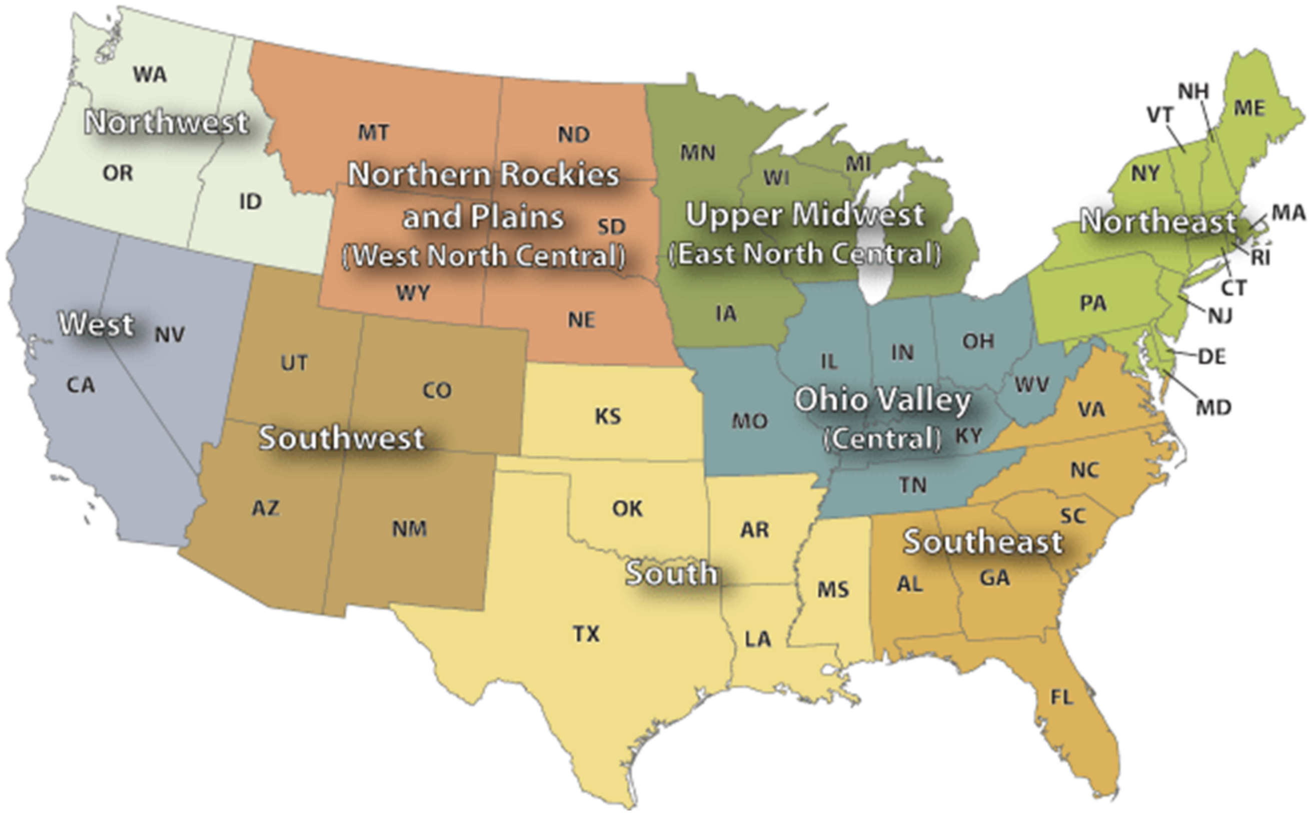
$\mathbf{S}_i$ = exporter i's features: cropland acreage, GDD, total precipitation, severe drought days, soil quality variables [Census of Agriculture, NARR, USGS] and accessibility index (Wei, 1996)

$\mathbf{M}_n$ = importer n's features: **food industry employment, ethanol and biodiesel capacity**, GDD, total precipitation, severe drought days, soil quality variables [BEA, USDA ERS, NARR, NOAA, USGS] and accessibility index (Wei, 1996)

ν_j = climate-region fixed effect of exporter i, ν_k= climate-region fixed effect of importer n

Nine U.S. climate regions

(National Oceanic and Atmospheric Administration)



Source: https://www.ncdc.noaa.gov/monitoring-references/maps/us-climate-regions.php#references

First stage results

Variable	Coef.	P-value	Variable	Coef.	P-value
Shared border	1.911	**0.000**	Severe drought days (orig.)	-0.415	**0.000**
One- to two-day trip	-1.170	**0.000**	Severe drought days (dest.)	0.153	**0.075**
Two- to three-day trip	-1.841	**0.000**	GDD (orig.)	3.408	**0.000**
Three- to four-day trip	-1.841	**0.000**	Precipitation (orig.)	-0.636	0.219
Four- to five-day trip	-2.270	**0.000**	GDD (dest.)	0.242	0.738
Five- or more day trip	-2.524	**0.000**	Precipitation (dest.)	-0.125	0.817
Cropland acreage (orig.)	0.787	**0.000**	K-ratio (orig.)	-3.013	**0.000**
Food industry (dest.)	1.081	**0.000**	Ksat_ratio (orig.)	-0.435	0.166
Biodiesel capacity (dest.)	0.016	0.563	Clay content (orig.)	-0.905	**0.012**
Ethanol capacity (dest.)	-0.012	0.468	K-ratio (dest.)	-0.652	0.317
Origin’s accessibility	1.542	0.138	Ksat_ratio (dest)	-0.611	**0.043**
Destination's accessibility	2.163	**0.001**	Clay content (dest)	-0.359	0.363

Adj. R sq = 0.36; Climate-region fixed effects not reported here.

Second stage -- Ricardian model

$$y_{i_j t} = \left(\widehat{\mathbf{W}}_t \mathbf{X}_{i_j t}\right)' \boldsymbol{\theta} + \mathbf{X}_{i_j t}' \boldsymbol{\beta} + \mathbf{T}_{i_j t}' \boldsymbol{\delta} + +\mathbf{C}_{i_j t}{}' \boldsymbol{\gamma} + \nu_j + \tau_t + \eta_{jt} + \epsilon_{i_j t} \qquad \epsilon_{i_j t} \sim N(0, \sigma_\epsilon^2)$$

i = 48 states, j = 9 climate regions, t = 4 years (1997, 2002, 2007, 2012), sample size: 192

y = agricultural profit from crop, fruits, veggies production [Census of Agriculture]

$\widehat{\mathbf{W}}$ = Predicted trade flows from the gravity model [global standardization]

X = crop demand variables: demand from food industries (food manufacturing employment) + demand from bioenergy industries (ethanol and biodiesel production capacity) [BEA, USDA ERS]

T = weather variables: GDD, GTP, severe drought days [NARR & NOAA]

C = Other controls: fertilizer expenditure per acre + share of irrigated farmland

+ soil quality variables (K-factor, K_{sat} rate, Clay content ratio) [Census of Agriculture, USGS]

ν_j = climate-region fixed effect, τ_t = year fixed effect, η_{jt} = climate-region-by-year fixed effect.

Ricardian model without and with trade

Variable name	**Coef.**	**P value**	**Coef.**	**P value**
Irrigation	0.004	0.630	0.007	0.387
Fertilizer	0.017	**0.000**	0.016	**0.000**
Local food industry employment	0.005	**0.007**	0.001	0.617
Local biofuel production capacity	0.000	0.178	0.000	0.864
Trade partners’ food industry			0.982	**0.040**
Trade partners’ biofuel capacity			0.110	0.116
Growing degree days	0.099	0.169	0.069	0.300
Growing degree days ^2	-0.001	0.227	-0.001	0.335
Total precipitation	0.086	**0.076**	0.088	**0.046**
Total precipitation ^ 2	-0.001	0.203	-0.002	**0.098**
Severe drought days	-0.001	0.154	-0.001	**0.069**
K ratio	-4.655	**0.069**	-5.362	**0.023**
Ksat ratio	-0.006	0.495	-0.005	0.536
Clay content	-0.018	0.386	-0.018	0.397
Adj. R sq	0.63		0.62	
BP test	75.245	**0.002**	70.252	**0.002**
Moran’s I test	0.034	0.216	0.046	0.151

Ricardian model with trade and structural break

Variable name	**Coef.**	**P value**
Irrigation	0.007	0.334
Fertilizer	0.016	**0.000**
Local food industry (small exporter)	-0.004	0.522
Local biofuel production capacity (small exporter)	0.001	**0.064**
Local food industry (large exporter)	0.000	0.925
Local biofuel production capacity (large exporter)	-0.000	0.786
Trade partners' food industry (small exporter)	1.078	**0.091**
Trade partners' biofuel production capacity (small exporter)	0.131	0.113
Trade partners' food industry (large exporter)	1.083	**0.030**
Trade partners' biofuel production capacity (large exporter)	0.118	0.239
Growing degree days	0.083	0.217
Growing degree days ^2	-0.001	0.231
Total precipitation	0.091	**0.032**
Total precipitation ^ 2	-0.002	**0.075**
Severe drought days	-0.001	**0.097**
K ratio	-5.592	**0.015**
Ksat ratio	-0.005	0.532
Clay content	-0.021	0.347
Adj. R sq	0.60	
BP test	84.826	**0.006**
Moran’s I test	0.024	0.318

Conclusion and future extensions

- Study the role of interstate trade in a Ricardian model using a panel dataset of 48 continental US states and 4 census years.
- A gravity model predicts the interstate trade flows and allows some climate variables to have an **indirect effect** on local agricultural profit (ex: severe drought days:

$\partial y_i/\partial x_{i,r} = \beta_{i,r}$ vs. $\partial y/\partial x_r = \sum_1^m \beta_m\left[(\partial w_{in}/\partial x_{i,r}) + (\partial w_{in}/\partial x_{n,r})\right]X_m + \beta_{i,r}.$

- Conclude that intermediate demand from the trader partners (mostly food industry) plays a **more important role** than local intermediate demand.
- Future extension I: **FAF4** data recently released=> panel gravity model
- Future extension II: **projected** climate variables (2038-2070) and trade flows (2045 FAF4 projections vs. our projections) → climate change adaptation through changes in the States' production structure and new trade flows (intensity and directionality)