14.581 International Trade
Lecture 7: Ricardian Assignment Models (Empirics)

Plan of Today's Lecture

1. Introduction to Ricardian assignment models
2. Empirical applications of Ricardian assignment models:
    1. Testing Ricardian comparative advantage: Costinot and Donaldson (2012a)
    2. Gains from economic integration: Costinot and Donaldson (2012b)
    3. Climate change and trade: Costinot, Donaldson and Smith (2012c)

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Introduction

- Today we look at Ricardian models from a slightly different perspective.
- In all of today's applications we will study economies where:
  - Each fundamental production unit uses one factor (land). This is of course Ricardian.
  - But the observable production units are comprised of many such fundamental production units, each of which is unique (i.e. the type of land is different).
  - Fundamental production units combine as perfect substitutes to generate output at the observable level.
  - So at the level of the observable production unit, this is an 'assignment model' of the comparative advantage and Ricardian sort.
  - See Costinot (Econometrica, 2009) for a discussion. Related also to David Autor's recent (2013) survey of the 'task-based' approach to studying labor markets, and to Grossman's recent (2013) survey of 'trade models with heterogeneous workers'.

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Motivation: A Famous Anecdote

- Stan Ulam once asked Paul Samuelson: ‘Name one proposition in the social sciences that is both **true** and **non-trivial**’
- Paul Samuelson’s reply: ‘Ricardo’s theory of comparative advantage’
- Truth, however, in Samuelson’s reply refers to the fact that Ricardo’s theory is **mathematically correct**, not **empirically valid**
- Goal of CD (2012a) is to develop and implement a test of Ricardo’s ideas

A Key Empirical Challenge

- Suppose that different factors of production specialize in different economic activities based on their relative productivity differences
- Following Ricardo's famous example, if English workers are relatively better at producing cloth than wine compared to Portuguese workers:
  - England will produce cloth
  - Portugal will produce wine
  - At least one of these two countries will be completely specialized in one of these two sectors
- Accordingly, the key explanatory variable in Ricardo's theory, relative productivity, cannot be directly observed

How Can One Solve This Identification Problem?

Existing Approach

- Previous identification problem is emphasized by Deardorff (1984) in his review of empirical work on the Ricardian model of trade
- A similar identification problem arises in labor literature in which self-selection based on CA is often referred to as the Roy model
  - Heckman and Honore (1990): if general distributions of worker skills are allowed, the Roy model has no empirical content
- One Potential Solution:
  - Make **untestable functional form assumptions** about distributions
  - Use these assumptions to relate observable to unobservable productivity
- Examples:
  - In a labor context: Log-normal distribution of worker skills
  - In a trade context: Fréchet distributions across countries and industries

How Can One Solve This Identification Problem?

This Paper's Approach

- Focus on sector in which scientific knowledge of how essential inputs map into outputs is uniquely well understood: **agriculture**
- As a consequence of this knowledge, agronomists can predict the productivity of a 'field' if it were to grow any one of a set of crops
- In this particular context, we know the productivity of a 'field' in *all* economic activities, not just those in which it is currently employed

Basic Theoretical Environment

- The basic environment is the same as in the purely Ricardian part of Costinot (2009)
- Consider a world economy comprising:
  - $c = 1, ..., C$ countries
  - $g = 1, ..., G$ goods [crops in our empirical analysis]
  - $f = 1, ..., F$ factors of production ['fields', or pixels, in our empirical analysis]
- Factors are immobile across countries, perfectly mobile across sectors
  - $L_{cf} \geq 0$ denotes the inelastic supply of factor f in country c
- Factors of production are perfect substitutes within each country and sector, but vary in their productivities $A_{cf}^{g} \geq 0$

Cross-Sectional Variation in Output

- Total output of good g in country c is given by

$$Q_c^g = \sum_{f=1}^{F} A_{cf}^g L_{cf}^g$$

- Take producer prices $p_c^g \geq 0$ as given and focus on the allocation that maximizes total revenue at these prices
- Assuming that this allocation is unique, can express output as

$$Q_c^g = \sum_{f \in \mathcal{F}_c^g} A_{cf}^g L_{cf} \quad (1)$$

where $\mathcal{F}_c^g$ is the set of factors allocated to good g in country c:

$$\mathcal{F}_c^g = \{ f = 1, ...F | \, A_{cf}^g / A_{cf}^{g'} > p_c^{g'} / p_c^g \text{ if } g' \neq g \} \quad (2)$$

Data Requirements

- CD (2012a)'s test of Ricardo's ideas requires data on:
  - Actual output levels, which we denote by $\widetilde{Q}_c^g$
  - Data to compute predicted output levels, which we denote by Q_c^g
- By equations (1) and (2), we can compute Q_c^g using data on:
  - Productivity, A_{cf}^g, for all factors of production f
  - Endowments of different factors, L_{cf}
  - Producer prices, p_c^g

Output and Price Data

- Output ($\widetilde{Q}_c^g$) and price (p_c^g) data are from FAOSTAT
- Output is equal to quantity harvested and is reported in tonnes
- Producer prices are equal to prices received by farmers net of taxes and subsidies and are reported in local currency units per tonne
- In order to minimize the number of unreported observations, our final sample includes 55 countries and 17 crops
- Since Ricardian predictions are cross-sectional, all data are from 1989

Productivity Data

- Global Agro-Ecological Zones (GAEZ) project run by FAO
  - Used in Nunn and Qian (2011) as proxy for areas where potato could be grown
- Productivity (A_{cf}^{g}) data for:
  - 154 varieties grouped into 25 crops c (though only 17 are relevant here)
  - All 'fields' f (5 arc-minute grid cells) on Earth
- Inputs:
  - Soil conditions (8 dimensional vector)
  - Climatic conditions (rainfall, temperature, humidity, sun exposure)
  - Elevation, average land gradient.
- Modeling approach:
  - Entirely 'micro-founded' from primitives of how each crop is grown.
  - 64 parameters per crop, each from field and lab experiments.
  - Different scenarios for other human inputs. We use 'mixed, irrigated'

Example: Relative Wheat-to-Sugar Cane Productivity

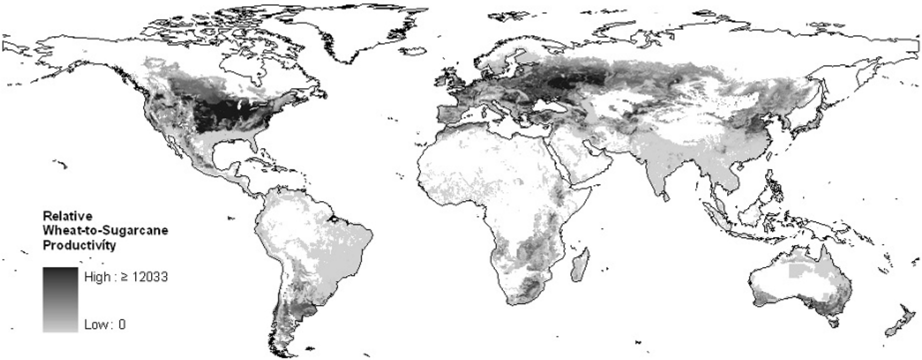

Figure 1: An Example of Relative Productivity Differences. Notes: Ratio of productivity in wheat (in tonnes/ha) relative to productivity in sugarcane (in tonnes/ha). Areas shaded white have either zero productivity in wheat, or zero productivity in both wheat and sugarcane. Areas shaded dark, with the highest value (">12,033"), have zero productivity in sugarcane and strictly positive productivity in wheat. Source: GAEZ project.

Empirical Strategy

- To overcome identification problem highlighted by Deardorff (1984) and Heckman and Honore (1990), CD (2012a) follow two-step approach:
  1. We use the GAEZ data to predict the amount of output (Q_c^g) that country c should produce in crop g according to (1) and (2)
  2. We regress observed output ($\widetilde{Q}_c^g$) on predicted output (Q_c^g)
- Like in HOV literature, they consider test of Ricardo's theory of comparative advantage to be a success if:
  - The slope coefficient in this regression is close to unity
  - The coefficient is precisely estimated
  - The regression fit is good
- Compared to HOV literature, CD (2012a) estimate regressions in logs:
  - Core of theory lies in how *relative* productivity predict *relative* quantities
  - *Absolute* levels of output off because more uses of land than 17 crops

Results

Table 1: Comparison of Actual Output to Predicted Output

Dependent variable:	log (output)				
	(1)	(2)	(3)	(4)	(5)
log (predicted output)	0.212***	0.244***	0.096**	0.143**	0.273***
	(0.057)	(0.074)	(0.038)	(0.062)	(0.074)
sample	all	all	all	major countries	major crops
fixed effects	none	crop	country	none	none
observations	349	349	349	226	209
R-squared	0.06	0.26	0.54	0.04	0.07

Notes: All regressions include a constant. Standard errors clustered by country are in parentheses. ** indicates statistically significant at 5% level and *** at the 1% level.

Concluding Remarks

- Ricardo's theory of CA is one of the oldest and most distinguished theories in economics, but it is a difficult theory to test
- To do so using conventional data sources, one needs to make untestable functional form assumptions
- CD (2012a) has argued that the predictions of agronomists can provide missing data required to test Ricardo's ideas
- And then CD (2012a) have shown that output levels predicted by Ricardo's theory of CA correlate surprisingly, but not that strongly, with those that are observed in the data

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How Large are the Gains from Economic Integration?

- Regions of the world, both across and within countries, appear to have become more economically integrated with one another over time.

- Two natural questions arise:

  1. How large have been the gains from this integration?

  2. How large are the gains from further integration?

How Large are the Gains from Economic Integration?

- Fundamental challenge lies in predicting how local markets would behave under **counterfactual scenarios** in which they become more or less integrated with rest of the world.
- In a Trade context, counterfactual scenarios typically involve the **reallocation of multiple factors of production** towards different economic activities.
- Hence researcher requires knowledge of **counterfactual productivity** of factors if they were employed in sectors in which producers are currently, and deliberately, not using them (Deardorff, 1984).
  - Any study of the gains from economic integration needs to overcome this **identification problem**.

How to Overcome Identification Problem?

- Four main approaches in the literature:
  - "Reduced form" approach (e.g. Frankel and Romer 1999): knowledge of CF obtained by observing behavior of "similar but open" countries.
  - "Autarky" approach (e.g. Bernhofen and Brown, 2005): autarky prices, when observed, are useful.
  - "Sufficient statistic" approach (e.g. Chetty, 2009): knowledge of CF technologies unnecessary (for small changes) because gains from reallocation of production are second-order at optimum.
  - "Structural" approach (e.g. Eaton and Kortum 2002): knowledge of CF obtained by extrapolation based on (untestable) functional forms.
- Basic idea of CD (2012b):
  - Develop new structural approach with weaker need for extrapolation by functional form assumptions.
  - Focus on sector of the economy with unique scientific knowledge of both **factual** and **counterfactual** productivity: **agriculture.**

CD (2012b): Method

- Consider a panel of ∼1,500 U.S. counties from 1880 to 1997.
  - Choose US for long sweep of high-quality, comparable micro-data from important agricultural economy.
- Use Roy/Ricardian model + FAO data to construct PPF in each county.
- Then two steps:
  1. **Measuring Farm-gate Prices:**
     - We combine Census data on output and PPF to infer prices that farmers in local market i appear to have been facing.
  2. **Measuring Gains from Integration:**
     - We compute the spatial distribution of price gaps between U.S. counties and New York/World in each year.
     - We then ask: "For any period t, how much higher (or lower) would the total value of US agricultural output in period t have been if price gaps were those from 1997 rather than those from period t?"

CD (2012b): Results

- Farm-gate price estimates look sensible:
  - State-level price estimates correlate well with state-level price data.
- How large have been the gains that arose as counties became increasingly integrated?
  - eg 1880-1920: **2.3 % growth (in agricultural GDP) per year**
  - same order of magnitude as productivity growth in agriculture

A Few Caveats to Keep in Mind

1. FAO data are only available in 2011.
   - Extrapoloation necessary when going back in time.
   - To do so CD (2012b) allow unrestricted county-crop-year specific productivity shocks.
2. Highest resolution output data available (from Census) is at county-level.
   - So direct predictions from high-resolution FAO model, pixel by pixel, are not testable.
3. Land (though heterogeneous) is the only factor of production.
   - Should think of land as "equipped" land

Related Literature

- "Reduced form" approach:
  - Frankel and Romer (1999), Feyrer (2009a, 2009b)
- "Structural" approach:
  - Anderson and van Wincoop (2003), Eaton and Kortum (2002), Eaton, Kortum and Kramarz (2011), Donaldson (2010), Waugh (2010), Arkolakis, Costinot, Rodriguez-Clare (2011), older CGE literature.
- Misallocation (based on departures from value marginal product equality across production units):
  - Restuccia and Rogerson (2008), Hsieh and Klenow (2009)
- With experimental control, can learn agents' counterfactual productivities:
  - Foster and Rosenzweig (1996)
- Economic history of domestic market integration:
  - Keller and Shiue (2008), Shiue (2005)

Basic Environment

- Many 'local' markets $i \in \mathcal{I} \equiv \{1, ..., I\}$ in which production occurs
- One 'wholesale' market in which goods are sold (New York/World)
- Only factors of production are fields $f \in \mathcal{F}_i \equiv \{1, ..., F_i\}$
  - $V_i^f \geq 0$ denotes the number of acres covered by field f in market i
- Fields can be used to produce multiple goods $k \in \mathcal{K} \equiv \{1, ..., K+1\}$
  - Goods $k = 1, ..., K$ are 'crops'; Good $K+1$ is an 'outside' good
- Total output Q_{it}^k of good k in market i is given by

$$Q_{it}^k = \sum_{f \in \mathcal{F}_i} A_{it}^{fk} L_{it}^{kf}$$

- All fields have same productivity in outside sector: $A_{it}^{fK+1} = \alpha_{it}^{K+1}$

Basic Environment (Continued)

- Large number of price-taking farms in all local markets.
- Profits of farm producing good k in local market i are given by:

$$\Pi_{it}^{k} = p_{it}^{k} \left[\sum_{f \in \mathcal{F}_i} A_{it}^{fk} L_{it}^{kf} \right] - \sum_{f \in \mathcal{F}_i} r_{it}^{f} L_{it}^{fk},$$

where farm-gate price of good k in local market i is given by:

$$p_{it}^{k} \equiv \bar{p}_{t}^{k} / (1 + \tau_{it}^{k}).$$

- Profit maximization by farms requires:

$$p_{it}^{k} A_{it}^{fk} - r_{it}^{f} \leq 0, \text{ for all } k \in \mathcal{K}, f \in \mathcal{F}_i, \quad (3)$$

$$p_{it}^{k} A_{it}^{fk} - r_{it}^{f} = 0, \text{ if } L_{it}^{fk} > 0, \quad (4)$$

- Factor market clearing in market i requires:

$$\sum_{k \in \mathcal{K}} L_{it}^{fk} \leq V_{i}^{f}, \text{ for all } f \in \mathcal{F}_i. \quad (5)$$

Competitive Equilibrium

- **Notation:**
  - $\bar{p}_t \equiv (\bar{p}_t^k)_{k \in \mathcal{K}}$ is exogenously given vector of wholesale prices
  - $p_{it} \equiv \left(p_{it}^k\right)_{k \in \mathcal{K}}$ is the vector of farm gate prices
  - $r_{it} \equiv (r_{it}^f)_{f \in \mathcal{F}}$ is the vector of field prices
  - $L_{it} \equiv (L_{it}^{fk})_{k \in \mathcal{K}, f \in \mathcal{F}}$ is the allocation of fields to goods in local market i

Definition

A competitive equilibrium in a local market i at date t is a field allocation, L_{it}, and a price system, (p_{it}, r_{it}), such that conditions (3)-(5) hold.

Two Steps of Analysis

- Recall that CD (2012b) break analysis down into two steps:

  1. **Measuring Farm-gate Prices:**
     - Combine data on output (from the Census) and the PPF (from the FAO) to infer the crop prices (p_{it}^k) that farmers in local market i appear to have been facing.

  2. **Measuring Gains from Integration:**
     - Compute price gaps $(1 + \tau_{it}^k)$ as the difference between farm-gate prices and prices in wholesale markets.
     - Then ask how much more productive a collection of local markets i would be under a particular counterfactual 'integration' scenario: all markets i face lower price gaps.

- Now describe how to do these steps in turn.

- The FAO aims for its measures of counterfactual productivity ($\hat{A}^{fk}_{i,2011}$) to be relevant today (ie in 2011). But how relevant are these measures for true technology (A^{fk}_{it}) in, eg, 1880?

- With data on both output and land use, by crop, CD (2012b) need only the following assumption:

$$A^{fk}_{it} = \alpha^{k}_{it} \hat{A}^{fk}_{i,2011}, \text{ for all } k = 1, ..., K, \ f \in \mathcal{F}_i.$$

- How realistic is this assumption?
  - The FAO runs model under varied conditions (eg irrigation vs rain-fed).
  - R^2 of $\ln \hat{A}^{fk}_{i,scenario2} - \ln \hat{A}^{fk}_{i,scenario1}$ on crop-county fixed effects is 0.78-0.82.
  - Results are insensitive to using these alternative scenarios.

Measuring Farm-gate Prices

- Dataset contains the following measures, which we assume are related to their theoretical analogues in the following manner:

$$
\begin{aligned}
\hat{S}_{it} &= \sum_{k=1}^{K} p_{it}^{k} Q_{it}^{k}, \\
\hat{Q}_{it}^{k} &= Q_{it}^{k}, \text{ for all } k = 1, ..., K, \\
\hat{L}_{it}^{k} &= \sum_{f \in \mathcal{F}_i} L_{it}^{fk}, \text{ for all } k = 1, ..., K, \\
\hat{V}_{i}^{f} &= V_{i}^{f}, \text{ for all } f \in \mathcal{F}_i .
\end{aligned}
$$

Definition

Given an observation $X_{it} \equiv [\hat{S}_{it}, \hat{Q}_{it}^{k}, \widehat{L}_{it}^{k}, \hat{V}_{i}^{f}, \hat{A}_{i,2011}^{fk}]$, a vector of productivity shocks and farm gate prices, (α_{it}, p_{it}), is *admissible* if and only if there exist a field allocation, L_{it}, and a vector of field prices, r_{it}, such that (L_{it}, p_{it}, r_{it}) is a competitive equilibrium consistent with X_{it}.

Measuring Farm-gate Prices

Notation

- For any observation X_{it}, we denote:
  - $\mathcal{K}_{it}^{*} \equiv \{k : \hat{Q}_{it}^{k} > 0\}$
  - $\mathcal{A}_{it}^{*} \equiv \{\alpha : \alpha^{k} > 0 \text{ if } k \in \mathcal{K}_{it}^{*}\}$
  - $\mathcal{P}_{it}^{*} \equiv \{p : p^{k} > 0 \text{ if } k \in \mathcal{K}_{it}^{*}\}$
  - $\mathcal{L}_{i} \equiv \left\{L : \sum_{k \in \mathcal{K}} L^{fk} \leq \hat{V}_{i}^{f}\right\}$
  - $L(\alpha_{it}, X_{it}) \equiv \arg\max_{L \in \mathcal{L}_{i}} \min_{k \in \mathcal{K}_{it}^{*}} \left\{\sum_{f \in \mathcal{F}_{i}} \alpha_{it}^{k} \hat{A}_{i,2011}^{fk} L^{fk} / \hat{Q}_{it}^{k}\right\}$

Theorem

For any $X_{it} \in \mathcal{X}$, the set of admissible vectors of productivity shocks and good prices is non-empty and satisfies: (i) if $(\alpha_{it}, p_{it}) \in \mathcal{A}^*_{it} \times \mathcal{P}^*_{it}$ is admissible, then $\left(\alpha^k_{it}\right)_{k \in \mathcal{K}^*_{it}/\{K+1\}}$ is equal to unique solution of

$$\sum_{f \in \mathcal{F}} \alpha^k_{it} \hat{A}^{fk}_{i2011} L^{fk}_{it} = \hat{Q}^k_{it} \text{ for all } k \in \mathcal{K}^*_{it} / \{K+1\}, \tag{6}$$

$$\sum_{f \in \mathcal{F}_i} L^{fk}_{it} = \hat{L}^k_{it} \text{ for all } k \in \mathcal{K}^*_{it} / \{K+1\}, \tag{7}$$

with $L_{it} \in L(\alpha_{it}, X_{it})$ and (ii) conditional on $\alpha_{it} \in \mathcal{A}^*_{it}$, $L_{it} \in L(\alpha_{it}, X_{it})$ satisfying (6) and (7), $(\alpha_{it}, p_{it}) \in \mathcal{A}^*_{it} \times \mathcal{P}^*_{it}$ is admissible iff

$$\sum_{k \in \mathcal{K}^*_i/\{K+1\}} p^k_{it} \hat{Q}^k_{it} = \hat{S}_{it},$$

$$\alpha^{k'}_{it} p^{k'}_{it} \hat{A}^{fk'}_{i2011} \leq \alpha^k_{it} p^k_{it} \hat{A}^{fk}_{i2011} \text{ for all } k, k' \in \mathcal{K},\ f \in \mathcal{F}_i, \text{ if } L^{fk}_{it} > 0.$$

Corollary

For almost all $X_{it} \in \mathcal{X}$, $\left(p_{it}^{k}\right)_{k \in \mathcal{K}_{it}^{*}/\{K+1\}}$ *is equal to the unique solution of*

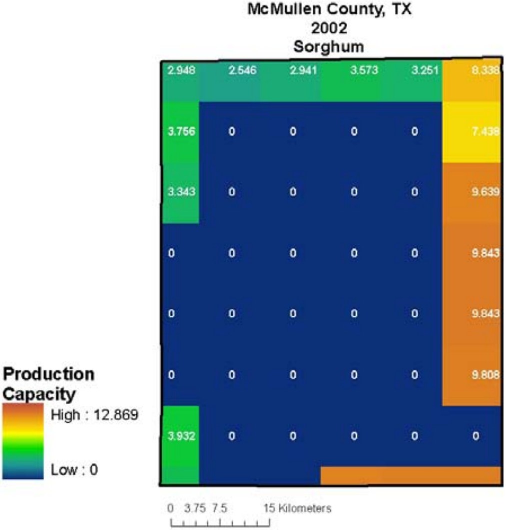
$$\sum_{k \in \mathcal{K}_{i}^{*}/\{K+1\}} p_{it}^{k} \hat{Q}_{it}^{k} = \hat{S}_{it},$$

$$\frac{p_{it}^{k'}}{p_{it}^{k}} = \frac{\alpha_{it}^{k} \hat{A}_{i2011}^{fk}}{\alpha_{it}^{k'} \hat{A}_{i2011}^{fk'}}, \text{ for any } f \in \mathcal{F}_{i} \text{ s.t. } L_{it}^{fk} \times L_{it}^{fk'} > 0,$$

where $\left(\alpha_{it}^{k}\right)_{k \in \mathcal{K}_{it}^{*}/\{K+1\}}$ *and* L_{it} *are as described in previous theorem.*

Measuring Farm-gate Prices

In practice, for a county that can be illustrated in 2-dimensions



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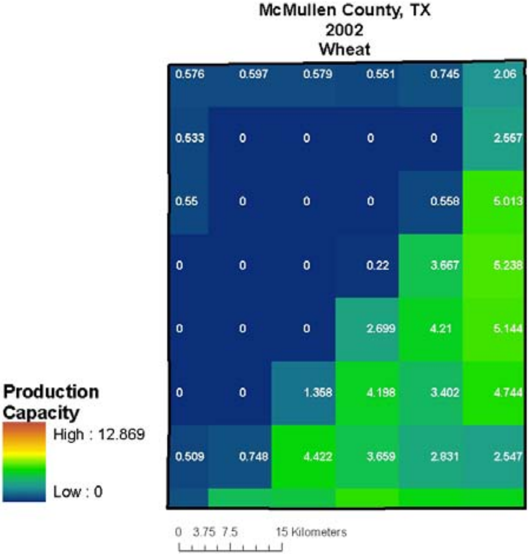

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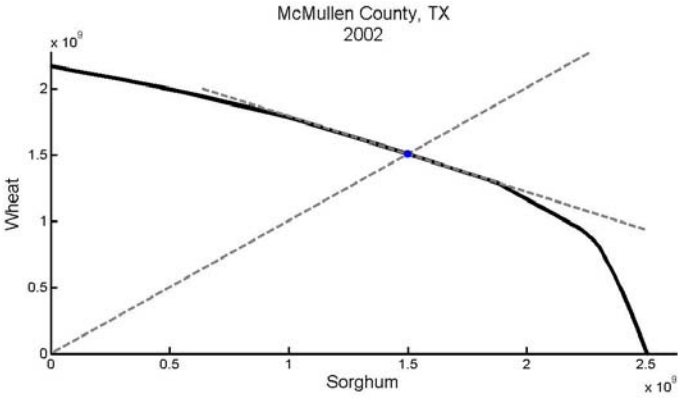

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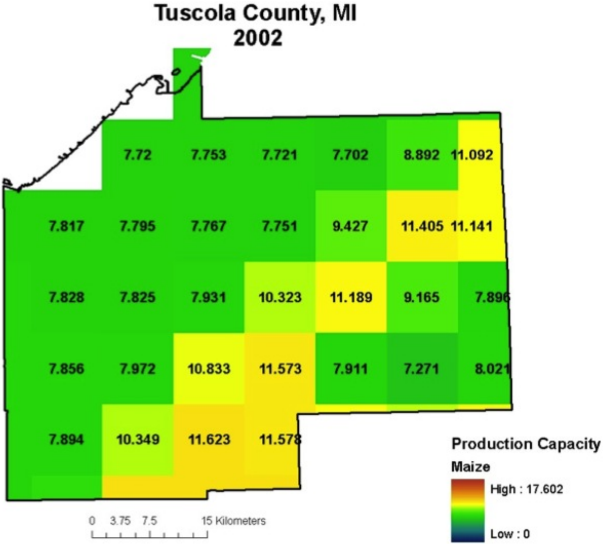

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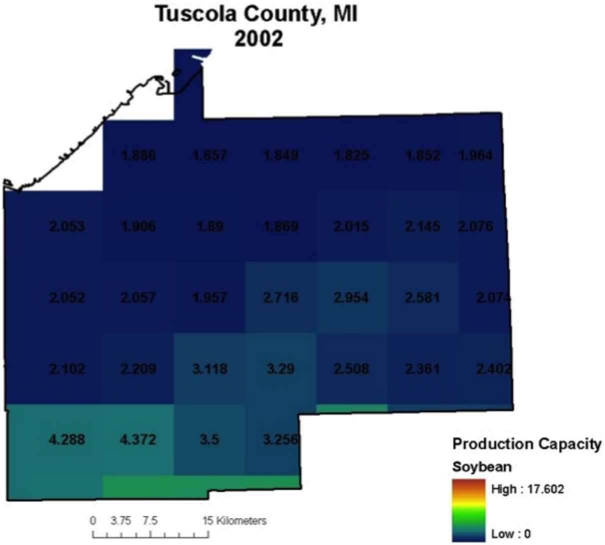

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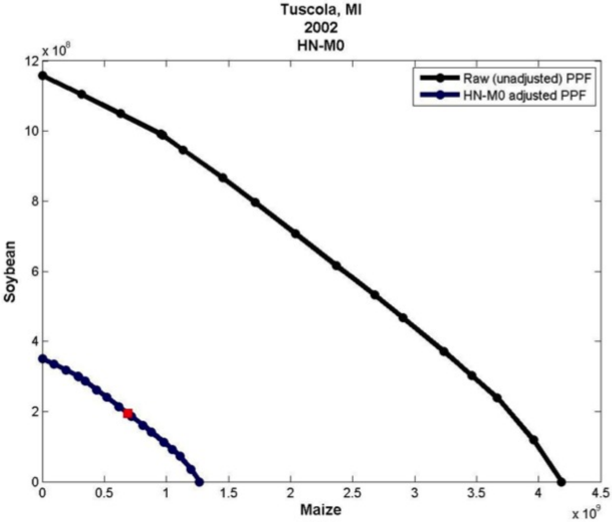

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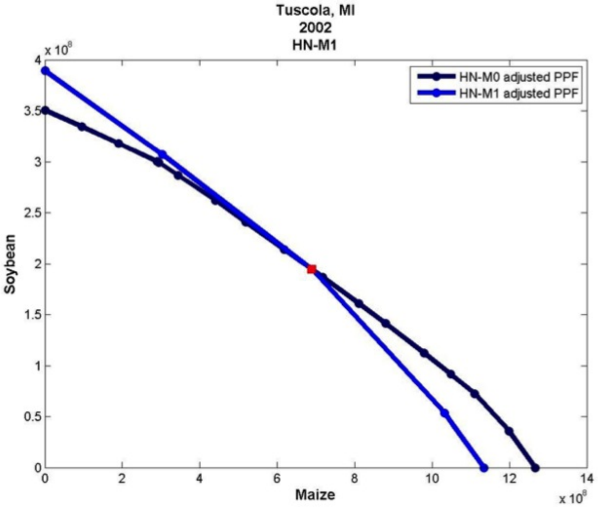

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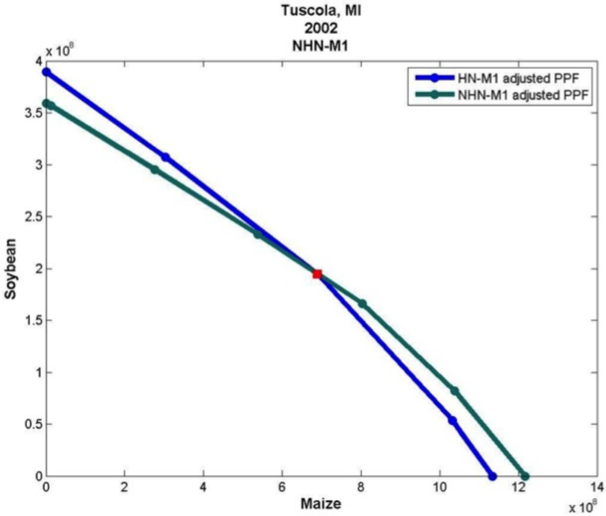


- Computation of α_{it} and p_{it} is non-trivial in high dimensional settings like those we consider.
  - For example, median county has $F = 26$ and $K^* = 8$.
  - Hence, $(K^*)^F = 3 \times 10^{23}$ fully specialized allocations to consider just to construct kinks of PPF.
  - Then $\sim$1,500 counties times 16 time periods.
- Theorem 1 is useful in this regard:
  - 'Inner loop': Conditional on α_{it}, farm-gate prices can be inferred by solving a simple linear programming problem.
  - 'Outer loop': α_{it} is relatively low-dimension (K^*).
- Paper develops algorithm that speeds up outer loop (standard algorithms too slow).

Measuring Gains from Economic Integration
Counterfactual

- Recall that CD (2012b)'s counterfactual question is:

  "For any pair of periods, t and t', how much higher (or lower) would the total value of agricultural output in period t have been if price gaps were those of period t' rather than period t?"

- Let $\left(Q_{it}^k\right)'$ denote counterfactual output level if farmers in market i were facing $\left(p_{it}^k\right)' = \bar{p}_t^k/(1+\tau_{it'}^k)$ rather than $p_{it}^k = \bar{p}_t^k/(1+\tau_{it}^k)$.

Then measure the gains (or losses) from changes in the degree of economic integration as:

$$\begin{aligned}
\Delta\tau_{t,t'}^{I} &\equiv \frac{\sum_{i\in\mathcal{I}}\sum_{k\in\mathcal{K}} \bar{p}_t^k \left(Q_{it}^k\right)'}{\sum_{i\in\mathcal{I}}\sum_{k\in\mathcal{K}} \bar{p}_t^k \hat{Q}_{it}^k} - 1, \\
\Delta\tau_{t,t'}^{II} &\equiv \frac{\sum_{i\in\mathcal{I}}\sum_{k\in\mathcal{K}} \left(p_{it}^k\right)' \left(Q_{it}^k\right)'}{{}_{i\in\mathcal{I}}\quad {}_{k\in\mathcal{K}}\, p_{it}^k \hat{Q}_{it}^k} - 1.
\end{aligned}$$

- Using the above framework it is easy to compare the gains from integration (ie $\Delta\tau^{I}_{t,t'}$ and $\Delta\tau^{II}_{t,t'}$) to the gains from pure agricultural technological progress.
- Let $\left(Q^k_{it}\right)''$ denote counterfactual output level if farmers in market i had access to $(\alpha^k_{it})'' = \alpha^k_{it'}$ rather than α^k_{it}, holding prices constant.
- Then compute gains from this change in agricultural technology:

$$\Delta\alpha_{t,t'} \equiv \frac{\sum_{i\in\mathcal{I}}\sum_{k\in\mathcal{K}} p^k_{it}\left(Q^k_{it}\right)''}{\sum_{i\in\mathcal{I}}\sum_{k\in\mathcal{K}} p^k_{it}\hat{Q}^k_{it}} - 1,$$

Measuring Gains from Economic Integration

Comments

- $\Delta\tau^{I}_{t,t'}$ and $\Delta\tau^{II}_{t,t'}$ both measure changes in GDP in agriculture in period t if price gaps were those of period t' rather than t.
- But $\Delta\tau^{I}_{t,t'}$ and $\Delta\tau^{II}_{t,t'}$ differ in terms of economic interpretation.
- For $\Delta\tau^{I}_{t,t'}$, we use reference prices to evaluate value of output.
  - Price gaps implictly interpreted as "true" distortions.
  - Similar to impact of misallocations on TFP in Hsieh Klenow (2009).
- For $\Delta\tau^{II}_{t,t'}$, we use local prices to evaluate value of output.
  - Price gaps implicitly interpreted as "true" productivity differences.
  - Similar to impact of trade costs in quantitative trade models

FAO Data: Limitations

- Potentially realistic farming conditions that do not play a role in the FAO model:
  - Increasing returns to scale in growth of one crop.
  - Product differentiation (vertical or horizontal) within crop categories.
  - Sources of complementarities across crops:
    - Farmers' risk aversion.
    - Crop rotation .
    - Multi-cropping.
- Potentially realistic farming conditions that are inconsistent with CD (2012b)'s application of the FAO model:
  - Changing use of non-land factors of production in response to changing prices of those factors. Introduces bias here if:
    - Relative factor prices implicitly used by FAO model differ from those in US 1880-1997,
    - and factor intensities differ across crops (among the crops that a county is growing).
  - Two seasons within a year (eg in some areas, cotton and wheat)

Agricultural Census Data

- Data on actual total output, $\hat{Q}_{it}^{k}$, and land use, $\hat{L}_{it}^{k}$, for:
  - Each crop k (barley, buckwheat, cotton, groundnuts, maize, oats, rye, rice, sorghum, soybean, sugarbeet, sugarcane, sunflower, sweet potato, wheat, white potato).
  - Each US county i (as a whole)
  - Each decade from 1840-1920, then every 5 years from 1950 to 1997.
- Data on total crop sales, $\hat{S}_{it}$, (slightly more than total sales just from our 16 crops) in county.
  - But this data starts in 1880 only.
  - Question asked of farmers changed between 1920 and 1950; comparisons difficult across these years (at the moment).
- Output and sales by county is the finest spatial resolution data available.

Price Data

- Key first step of our exercise is estimation of farm-gate prices.
- Natural question: how do those prices correlate with real producer price data?
- Only available producer price data is at the state-level (with unknown sampling procedure within states):
  - 1866-1969: ATICS dataset (Cooley et al, 1977), generously provided by Paul Rhode.
  - 1970-1997: supplemented with data from NASS/USDA website.

Empirical Results

- **Step 1: Measuring Farm-gate Prices**
  - Do the estimated farm-gate prices look sensible?
  - Do the estimated productivity shifters look sensible?
- **Step 2: Measuring Gains from Integration**
  - How large are these gains?

Do Estimated Farm-gate Prices Look Sensible?

Table 1: Correlation between estimated prices and price data

Dep. variable:	estimated price (from model)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
observed producer price (from real world)	0.810*** (0.0186)	0.713*** (0.0215)	0.680*** (0.0336)	0.692*** (0.0395)	1.049*** (0.00553)	0.842*** (0.0217)	0.804*** (0.0258)	0.835*** (0.0506)
Logs or levels	Levels	Levels	Levels	Levels	Logs	Logs	Logs	Logs
constant	No	Yes	Yes	Yes	No	Yes	Yes	Yes
crop fixed effect	No	No	Yes	Yes	No	No	Yes	Yes
year fixed effect	No	No	No	Yes	No	No	No	Yes
R-squared	0.408	0.285	0.370	0.431	0.929	0.352	0.614	0.714
observations	2,766	2,766	2,766	2,766	2,766	2,766	2,766	2,766

Notes: Robust standard errors, clustered at the state-level, in parentheses. *** indicates statistically significant at 0.1% level. Columns (1) and (5) report uncentered R-squared values.

Gains from Economic Integration: Question

- Recall the counterfactual question of interest:

  How much higher (or lower) would the total value of output across local markets in period t have been if price gaps were those of period t' rather than period t?

- Requires two years, t and t'.
  - For now pick $t' = 1920$ or 1997

Gains from Economic Integration: Procedure

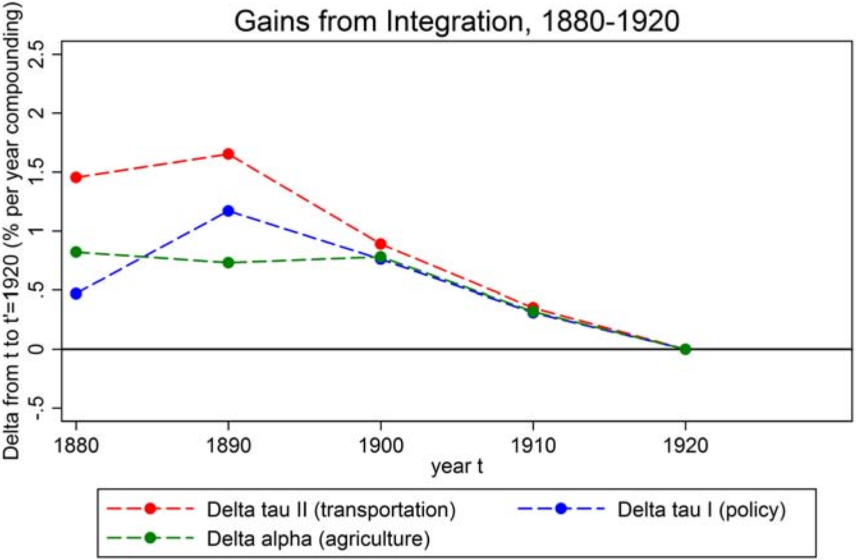
1. Define counterfactual farm-gate prices in year t as: $\left(p_{it}^{k}\right)' = \bar{p}_{t}^{k} / \left(1 + \tau_{it'}^{k}\right)$.

2. Compute counterfactual output levels $\left(Q_{it}^{k}\right)'$.

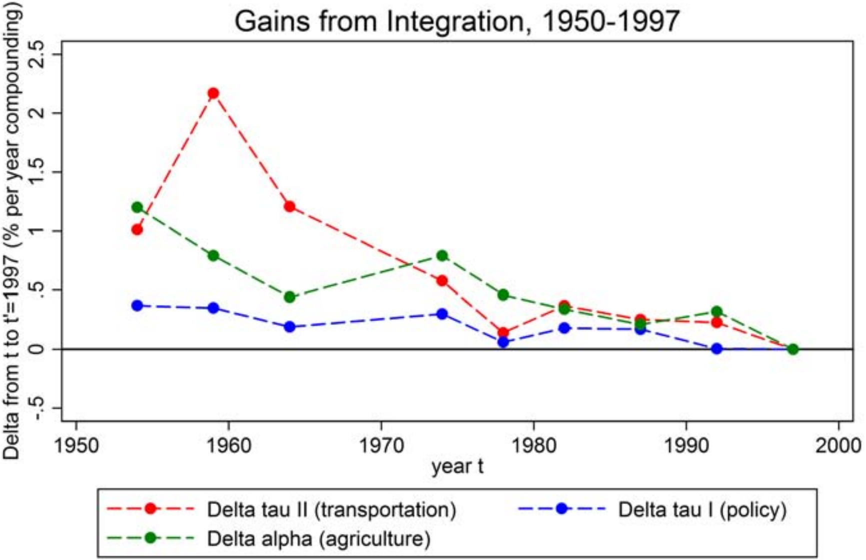
3. Compute gains from counterfactual scenario using:

$$\begin{aligned}
\Delta\tau_{t,t'}^{I} &\equiv \frac{\sum_{i\in\mathcal{I}}\sum_{k\in\mathcal{K}} \bar{p}_{t}^{k}\left(Q_{it}^{k}\right)'}{\sum_{i\in\mathcal{I}}\sum_{k\in\mathcal{K}} \bar{p}_{t}^{k}\hat{Q}_{it}^{k}} - 1, \\
\Delta\tau_{t,t'}^{II} &\equiv \frac{\sum_{i\in\mathcal{I}}\sum_{k\in\mathcal{K}} \left(p_{it}^{k}\right)'\left(Q_{it}^{k}\right)'}{\sum_{i\in\mathcal{I}}\sum_{k\in\mathcal{K}} p_{it}^{k}\hat{Q}_{it}^{k}} - 1, \\
\Delta\alpha_{t,t'} &\equiv \frac{\sum_{i\in\mathcal{I}}\sum_{k\in\mathcal{K}} p_{it}^{k}\left(Q_{it}^{k}\right)''}{\sum_{i\in\mathcal{I}}\sum_{k\in\mathcal{K}} p_{it}^{k}\hat{Q}_{it}^{k}} - 1.
\end{aligned}$$

Gains from Economic Integration: Estimates



Gains from Economic Integration: Estimates



Summary

- CD (2012b) have developed a new approach to measuring the gains from economic integration based on Roy/Ricardian model.
- Central to the approach is use of novel agronomic data:
  - Crucially, this source aims to provide *counterfactual productivity data*: productivity of all crops in all regions, not just the crops that are actually being grown there.
- Have used this approach to estimate:
  1. County-level prices for 16 main crops, 1880-1997.
  2. Changes in spatial distribution of price gaps across U.S. counties from 1880 to 1997: estimated gaps appear to have fallen over time.
  3. Gains associated with reductions in the level of these gaps of the same order of magnitude as productivity gains in agriculture

Plan of Today's Lecture

1. Introduction to Ricardian assignment models
2. Empirical applications of (Ricardian) assignment models:
    1. Testing Ricardian comparative advantage: Costinot and Donaldson (2012a)
    2. Gains from economic integration: Costinot and Donaldson (2012b)
    3. **Climate change and trade: Costinot, Donaldson and Smith (2012c)**

Climate Change and Agriculture: from Micro to Macro

- Voluminous agronomic literature establishes that climate change will hurt important crops in many locations on Earth
  - See review in IPCC, 2007, Chapter 5
- Agronomists provide very detailed micro-level estimates
  - Predictions about implications of climate change for crop yields, crop by crop and location by location
- Goal of this paper is to aggregate up micro-agronomic estimates in order to shed light an important macro-economic question:
  - **What will be the global impact of climate change on the agricultural sector?**

The Impact of Climate Change in a Globalized World

- Analysis in CD (2012c) builds on one simple observation:
  - **When countries can trade, the impact of micro-level shocks does not only depend on their average level, but also on their dispersion over space, i.e., their effect on comparative advantage**
- Basic idea:
  - A wheat farmer cares not only about what CC does to his wheat yields
  - He also cares about what CC does to the yields of the crops that he could have produced as well as their (relative) prices, which depend on how other farmers' (relative) yields are affected around the world
- Note: **This is not 'trade as adaptation'**:
  - Trade openness can mitigate the ill-effects of climate change if it leads to more heterogeneity in productivity within and between countries
  - Trade openness can exacerbate the ill-effects of climate change if it leads to less heterogeneity in productivity within and between countries

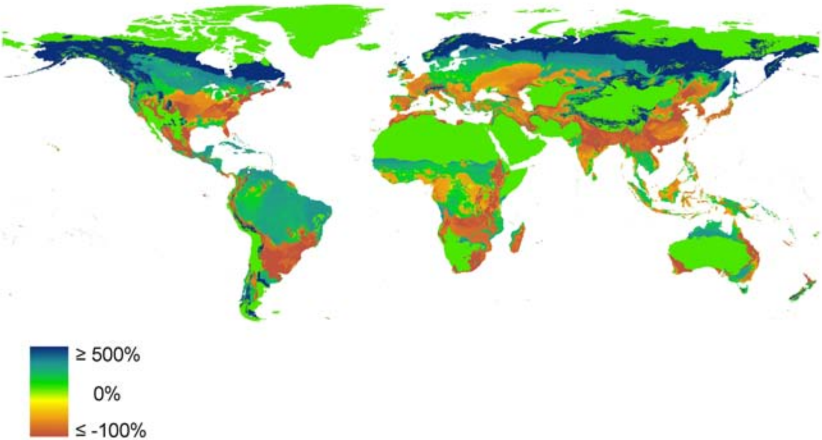
Empirical Strategy

- CD (2012c) use the Food and Agriculture Organization's (FAO) Global Agro-Ecological Zones (GAEZ) dataset
  - 9 million grid-cells ('fields') covering surface of the Earth
  - State-of-the-art agronomic models used to predict yield of any crop at each grid cell (on basis of soil, topography, climate, etc.)

- Key attractive features of GAEZ dataset:
  - Measuring comparative advantage is impossible using conventional data (need to observe how good a farmer is at doing what he doesn't do)
  - Exact same agronomic model used to model 'baseline' and 'climate change' scenarios; just different climate inputs (plus CO_2 fertilization)
  - 9 million grid cells means plenty of scope for within-country heterogeneity (which turns out to be important)

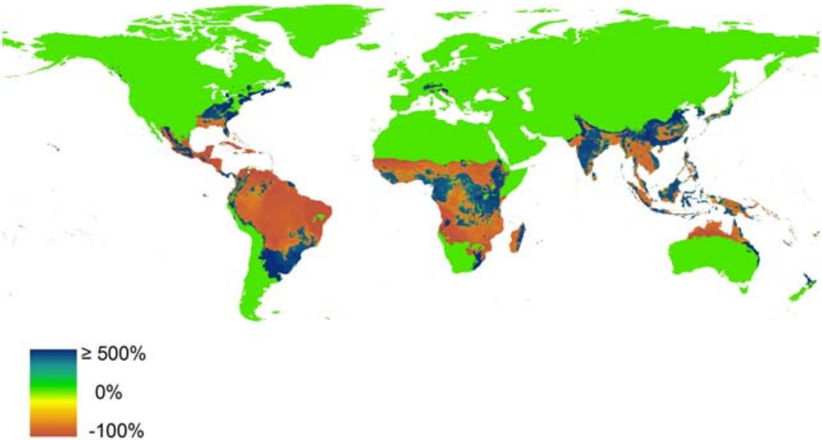
Predicted Change in Productivity due to Climate Change

Example: % change in wheat



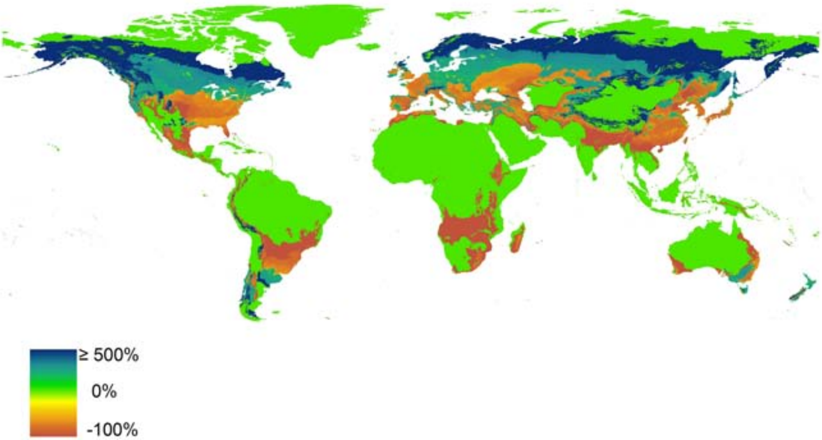
Predicted Change in Productivity due to Climate Change

Example: % change in rice



Predicted Change in Comparative Advantage due to CC

Example: Difference between wheat % change and rice % change



Beyond the GAEZ data

- Aggregating up the GAEZ data requires an economic model:
  - Maximizing agents (consumers and farmers)
  - Barriers to trade between countries
  - General equilibrium (supply = demand in all crops and countries)
  - A metric for aggregate welfare
- CD (2012c) construct a quantitative trade model with:
  - Estimate 3 key parameters using 3 transparent data moments
  - Evaluate goodness of fit on other moments
  - Solve model under baseline and climate change GAEZ scenarios

Related Literature on Trade and Climate Change

- **Carbon leakages:**
  - Felder and Rutherford (1993), Babiker (2005), Elliott, Foster, Kortum, Munson, Cervantes, Weisbach (2010) and Hemous (2012)
- **International transportation:**
  - Cristea, Hummels, Puzzello, and Avetysyan (2012), Shapiro (2012)
- **Trade and adaptation to CC in agriculture (CGE):**
  - Reilly and Hohmann (1993), Rosenzweig and Parry (1994), Tsigas, Friswold, and Kuhn (1997), and Hertel and Randhir (1999)

Basic Environment

- Multiple countries $i \in \mathcal{I} \equiv \{1, ..., I\}$
- Only factors of production are fields $f \in \mathcal{F}_i \equiv \{1, ..., F_i\}$
  - Fields should be thought of as equipped land
  - Each field comprises continuum of parcels $\omega \in [0, 1]$
  - All fields have the same size, normalized to one
- Fields can be used to produce multiple goods $k \in \mathcal{K} \equiv \{0, ..., K\}$
  - Goods $k = 1, ..., K$ are 'crops'
  - Good 0 is an 'outside' good

Preferences and Technology

- Representative agent in each country with two-level utility function:

$$
\begin{aligned}
U_i &= \prod_{k=0}^{K} \left(C_i^k\right)^{\beta_i^k} \\
C_i^k &= \left(\sum_{j=1}^{I} \left(c_{ji}^k\right)^{\left(\sigma^k-1\right)/\sigma^k}\right)^{\sigma^k/\left(\sigma^k-1\right)}
\end{aligned}
$$

- Total output Q_i^k of good k in country i:

$$
Q_i^k = \sum_{f \in \mathcal{F}_i} \int_0^1 A_i^{fk}(\omega) L_i^{fk}(\omega) \, d\omega
$$

with productivity of each parcel ω such that:

$$
\begin{aligned}
\ln A_i^{fk}(\omega) &= \ln A_i^{fk} + \varepsilon_i^{fk}(\omega) \\
A_i^{fk} &= E\left[A_i^{fk}(\omega)\right]
\end{aligned}
$$

Market Structure and Trade Costs

- All markets are perfectly competitive
- Trade is (potentially) costly:
  - Trade in crops $k = 1, ..., K$ is subject to iceberg trade costs, $\tau_{ij}^{k} \geq 1$
  - Normalize such that $\tau_{ii}^{k} = 1$
  - No arbitrage between countries implies:

$$p_{ij}^{k} = \tau_{ij}^{k} p_{i}^{k}$$

  - Outside good (i.e. $k = 0$) is not traded

Competitive Equilibrium

- Consumers maximize utility:

$$C_i^0 = \frac{\beta_i^0 Y_i}{p_i^0} \tag{8}$$

$$C_{ji}^k = \frac{\left(\tau_{ji} p_j^k\right)^{-\sigma^k}}{\sum_{j'=1}^{I} \left(\tau_{j'i} p_{j'}^k\right)^{1-\sigma^k}} \beta_i^k Y_i \tag{9}$$

- Firms maximize profits:
  - Share of parcels of field f allocated to good k in country i:

$$\pi_i^{fk} = \Pr\left\{ \frac{A_i^{fk}(\omega)}{A_i^{fl}(\omega)} > \frac{p_i^l}{p_i^k} \text{ if } l \neq k \right\} = \frac{\left(p_i^k A_i^{fk}\right)^{\theta}}{\sum_{l \in \mathcal{K}} \left(p_i^l A_i^{fl}\right)^{\theta}}.$$

  - Given factor allocation, total output for good k in country i:

$$Q_i^k = \sum_{f \in \mathcal{F}_i} A_i^{fk} \left(\pi_i^{fk}\right)^{(\theta-1)/\theta} \tag{10}$$

Competitive Equilibrium (Continued)

- Goods markets clear:

$$Q_i^0 = C_i^0 \tag{11}$$
$$Q_i^k = \sum_{j \in \mathcal{I}} \tau_{ij} C_{ij}^k \tag{12}$$

Definition

A competitive equilibrium is a set of producer prices, $\mathbf{p}$, output levels, $\mathbf{Q}$, and consumption levels, $\mathbf{C}$, such that Equations (8)-(12) hold

- Once CD (2012c) have estimates of parameters (see below) they compute competitive equilibria for this economy:
  - at baseline ($\sim$ 2009), to assess model fit and provide model-consistent benchmark
  - under the new productivity levels $\left(\hat{A}_i^{fk}\right)'$ that obtain under climate change (2071-2100), with full adjustment

Model Parameter Estimation

Overview

- Model contains the following unknown parameters:
  - Preferences: β_i^k and σ^k
  - Technology: $p_i^0 A_i^0$ and θ
  - Trade costs: τ_{ij}^k
- CD (2012c) estimate these parameters using a cross-section of FAO and GAEZ data from 2009

- Let X_{ij}^k denote the value of exports of crop k from i to j
- With measurement error (η_{ij}^k) in trade flows, Equation (9) implies

$$\ln X_{ij}^k = E_i^k + M_i^k + \left(1 - \sigma^k\right) \ln \tau_{ij} + \eta_{ij}^k$$

- Estimate σ^k by OLS treating E_i^k and M_j^k as fixed effects
  - For now, set $\sigma^k = \sigma$ for all $k = 1...K$ for simplicity
- Finally, use trade and output data to measure expenditure shares:

$$\widehat{\beta}_i^k = \frac{\sum_{j \neq i} X_{ji}^k + \left(p_i^k Q_i^k - \sum_{j \neq i} X_{ij}^k\right)}{GDP_i}$$

Estimation Procedure

Step 2: Technology

- For crops $(k = 1...K)$, the GAEZ data provides plausibly unbiased estimate $\hat{A}_i^{fk}$ of $E\left[A_i^{fk}(\omega)\right] = A_i^{fk}$.

- CD (2012c) use output and producer price data to estimate θ by NLS:

$$\min_{\theta} \sum_{i,k\neq 0} \left(\ln \tilde{Q}_i^k(\theta) - \ln Q_i^k\right)^2,$$

where $\tilde{Q}_i^k(\theta)$ is output level predicted by model

$$\tilde{Q}_i^k(\theta) = \sum_{f\in\mathcal{F}_i} \hat{A}_i^{fk} \left(\frac{\left(p_i^k \hat{A}_i^{fk}\right)^\theta}{\sum_{l\in\mathcal{K}} \quad p_i^l \hat{A}_i^{fl} \quad ^\theta}\right)^{(\theta-1)/\theta}$$

- For outside good they estimate $p_i^0 A_i^0 \equiv p_i^0 Q_i^0 / L_i^0$ from GDP (to compute $p_i^0 Q_i^0$) and land data (i.e. L_i^0)

- Data on origin-destination price gaps used to estimate τ_{ij}^k
- Following a standard free arbitrage argument, for crops and country-pairs with positive trade flows, we compute:

$$\ln \tau_{ij}^k = \ln p_{ij}^k - \ln p_i^k$$

- Then assume that for all crops and country-pairs:

$$\ln \tau_{ij}^k = \alpha \ln d_{ij} + \varepsilon_{ij}^k$$

- Where d_{ij} is the great circle distance between major population centers (from CEPII 'gravity' dataset) and ε_{ij}^k is an error term.
    - Straightforward to extend this method to include a full vector of trade cost determinants (e.g. contiguity, shared language, colonial ties, etc.)
- Estimate α by OLS and use $\alpha \ln d_{ij}$ as our measure of trade costs, ie:

$$\ln \widehat{\tau}_{ij}^k = \widehat{\alpha} \ln d_{ij}$$

GAEZ Data: Productivity after Climate Change

- At baseline:
  - Climatic conditions obtained from daily weather records, 1961-1990
  - Agronomic model simulated in each year
  - Reported $\hat{A}_i^{fk}$ is average over these 30 years of runs.
- Under climate change:
  - Exact same agronomic model, just different climatic data. (NB: this means that adaptation through technological change, etc is shut down.)
  - Reported $\left(\hat{A}_i^{fk}\right)'$ is average over 30 years of agronomic model runs from 2071-2100
  - 'Weather' from 2071-2100 from Hadley CM3 A1F1 global circulation model (GCM).
  - Also allow for CO_2 fertilization effect in plants

Other Sources of Data: FAOSTAT, World Bank

- From FAOSTAT obtain data on the following (for all countries i and crops k, in 2009):
  - Q_i^k, output [tonnes]
  - p_i^k, producer price [USD/tonne]
  - L_i^0, land used by outside good [ha]
  - X_{ij}^k, exports [USD]
  - p_{ij}^k, import (cif) price [USD/tonne]

- From World Bank obtain data on (for all countries i, in 2009):
  - $p_i^0 Q_i^0$, value of output of outside good [USD]

Estimation Results

Table 2: Parameter estimates

Parameter	Description	Parameter estimate	Parameter standard error
α	Elasticity of trade costs with respect to distance	0.110	(0.003)
θ	Within-field heterogeneity dispersion (and within-field elasticity of substitution in supply)	2.571	[2.378,2.666]
σ	Elasticity of substitution in demand (across varieties of a crop)	17.864	(0.772)

Notes: Parameter estimates using method described in Section 5. Standard errors for α and σ are clustered at the country level. The reported standard error for θ is the 95% confidence interval obtained from a bootstrap procedure with 340 replications.

Model Fit

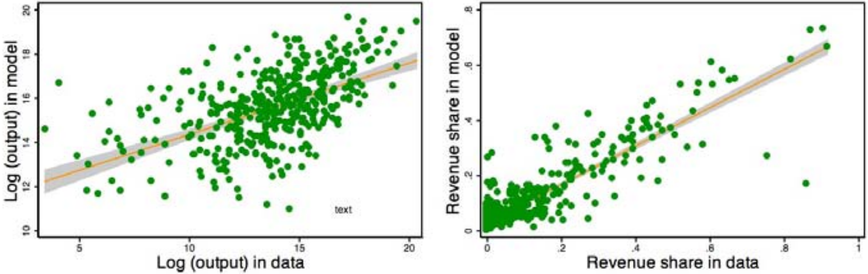


Figure 2(a) Figure 2(b)

Notes: Panel (a) plots log output computed in the model (y-axis) against log output in the FAO data (x-axis), across all crops and countries. Panel (b) reports the analogous comparison between revenue shares (by crop and country) in the model and the data. Best fit line and 95% confidence interval are also indicated.

Counterfactual Scenarios

- Three scenarios (each compared with relevant baseline), designed to illustrate GE mechanisms at work here
- **Scenario 1:**
  - Climate Change, Trade Costs at Baseline, Full Output Adjustment
  - "True" Impact
- **Scenario 2**:
  - Climate Change, Trade Costs at Baseline, No Output Adjustment
  - Gains from "Local Specialization" $\equiv \neq$ between 2 and 1
- **Scenario 3**:
  - Climate Change, Autarky, Full Output Adjustment
  - Gains from "International Specialization" $\equiv \neq$ between 3 and 1

Main Counterfactual simulation results

Table 3: Counterfactual simulation results (trade vs autarky)

	Change in real income due to climate change under scenario...		Difference between Trade (1) and Autarky (2) scenarios	Change in real income (expressed as a percentage of agricultural expenditure) due to climate change under scenario...		Difference between Trade (4) and Autarky (5) scenarios
	Trade costs,with full output reallocation	Autarky, with full output reallocation		Trade costs,with full output reallocation	Autarky, with full output reallocation	
	(1)	(2)	(3)	(4)	(5)	(6)
World median	-0.16%	-0.06%	-0.01%	-5.2%	-2.9%	-0.2%
10th percentile	-1.89%	-1.98%	-0.17%	-35.8%	-38.3%	-5.5%
90th percentile	0.57%	0.67%	0.53%	16.4%	16.6%	4.6%

Notes: Column (1) reports the change in real income, between the model under baseline and the model under climate change, when trade costs are at the level estimated in the baseline sample (as outlined in Section 5). Column (2) reports the analogous results to column (1) for the case where trade costs are set to infinity (in both baseline and under climate change). Column (3) reports the difference between the result in columns (1) and (2), for the median, 10th and 90th percentile countries; because the identities of these countries differ across columns (1) and (2), the entires in column (3) are not equal to the difference between those in columns (1) and (2). Columns (4) through (6) report analogous results to those in columns (1) through (3) but with all numbers divided by the agricultural (for the 10 crops in our sample) expenditure share of the country in question. Source: authors' estimates as described in Sections 3, 5 and 6.

Main Counterfactual simulation results

Table 4: Counterfactual results (reallocation vs non-reallocation)

	Change in real income due to climate change under scenario...		Difference between Reallocation (1) and Non-reallocation (2) scenarios	Change in real income (expressed as a percentage of agricultural expenditure) due to climate change under scenario...		Difference between Reallocation (1) and Non-reallocation (2) scenarios
	Trade costs,with full output reallocation	Trade costs,with no output reallocation		Trade costs,with full output reallocation	Trade costs,with no output reallocation	
	(1)	(2)	(3)	(4)	(5)	(6)
World median	-0.16%	-1.58%	1.14%	-5.2%	-34.7%	30.4%
10th percentile	-1.89%	-5.07%	0.2%	-35.8%	-78.3%	10.4%
90th percentile	0.57%	-0.05%	4.0%	16.4%	-3.7%	56.6%

Notes: Column (1) reports the change in real income, between the model under baseline and the model under climate change, when trade costs are at the level estimated in the baseline sample (as outlined in Section 5) and production is allowed to reallocate between the baseline and climate change scenarios. Column (2) reports the analogous results to column (1) for the case where production is not allowed to reallocate. Column (3) reports the difference between the result in columns (1) and (2), for the median, 10th and 90th percentile countries; because the identities of these countries differ across columns (1) and (2), the entires in column (3) are not equal to the difference between those in columns (1) and (2). Columns (4) through (6) report analogous results to those in columns (1) through (3) but with all numbers divided by the agricultural (for the 10 crops in our sample) expenditure share of the country in question. Source: authors' estimates as described in Sections 3, 5 and 6.

Counterfactual simulation results—Robustness

Table 5: Counterfactual simulation results (robustness)

	Effects of climate change on real income (expressed as percentage of agricultural expenditure) under modeling assumption and scenario...							
	Baseline		Generalized CES preferences		Unrestricted crop- and country-specific productivity adjustments to GAEZ data		Tradable outside sector	
	Trade	Autarky	Trade	Autarky	Trade	Autarky	Trade	Autarky
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
World median	-5.2%	-2.9%	-4.9%	-1.7%	-2.5%	-1.6%	-3.5%	-3.0%
10th percentile	-35.8%	-38.3%	-39.8%	-37.1%	-16.3%	-14.7%	-40.7%	-35.6%
90th percentile	16.4%	16.6%	11.1%	10.7%	3.2%	3.5%	11.8%	17.3%

Notes: Column (1) reports the change in real income, between the model under baseline and the model under climate change, when trade costs are at the level estimated in the baseline sample (as outlined in Section 5). Column (2) reports the analogous results to column (1) for the case where trade costs are set to infinity (in both baseline and under climate change). Columns (3) and (4) report analogous results to those in (1) and (2) but for a version of the model in which preferences are generalized CES (rather than Cobb-Douglas), with CES parameter γ=20.45, as described in Section 7.1. Columns (5) and (6) report analogous results to those in (1) and (2) but for a version of the model in which first we estimate crop- and country-specific unrestricted productivity adjustments to the GAEZ data, as described in Section 7.2. Columns (7) and (8) report analogous results to those in (1) and (2) but for a version of the model in which the outside sector is assumed to be freely tradable (rather than non-tradable), as described in Section 7.3. Source: authors' estimates as described in Sections 3, 5, 6 and 7.

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