The U.S. Biofuel Mandate and World Food Prices: An Econometric Analysis of the Demand and Supply of Calories

Michael Roberts[1] Wolfram Schlenker[2]

[1]North Carolina State University

[2]Columbia University and NBER

Columbia - February 15, 2010

Outline

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Background - World Food Prices

- Recent threefold increase in price of maize
  - Between Summer 2006 and Summer 2008
  - Prices for wheat, soybeans, and rice increased as well
- Food is basic commodity
  - Rising hunger and malnutrition
  - Potential for increased conflict

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    - New York Times: consumers in developing countries, not U.S. cut back on food consumption
  - Potential for increased conflict
    - Miguel et el.(2004): weather induced income shocks lead to civil conflict in Africa
    - Most African countries are net food importers
    - Increase in price implies reduction in real income

Background - World Food Prices

Across Globe, Empty Bellies Bring Rising Anger

Tyler Hicks/The New York Times

In a garbage dump in Port-au-Prince, people recently scavenged for food. More Photos >

By MARC LACEY
Published: April 18, 2008

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- Possible explanations for threefold price increase
  - Detrimental weather
    - Prolonged drought in Australia
  - Rising oil price
  - Increased demand for meat (China and India)
    - China: 33fold increase in per-capita meat consumption (1961-2006)
    - Meat requires 5-10 times the area per calorie
    - 20% reduction in U.S. meat consumption equivalent to switching from Camry to Prius
  - U.S. ethanol subsidies / mandate

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- Environmental Protection Agency
  - Recent Report (February 4th)
    - Net CO_2 reduction
    - Advocates increased use of biofuels
  - Driving forces behind analysis
    - Increased yield per acre
    - Little area expansion required
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- Estimate supply / demand for calories
  - Calories: aggregate maize, wheat, rice, and soybeans
  - Instrument: Yield Shock (deviations from trend)
  - Identification of Demand
    - Current yield shock shifts supply-curve
    - Used since P.G. Wright introduced IV (1928)
  - Identification of Supply
    - Past yield shocks shift expected price
    - Instrument futures price in supply equation
    - New extension: Previous estimates find inelastic supply, yet simulations use positive elasticity
- Assess U.S. ethanol mandate

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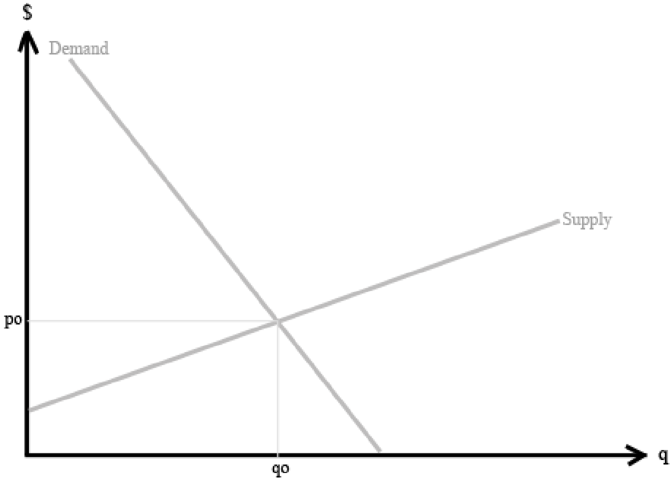

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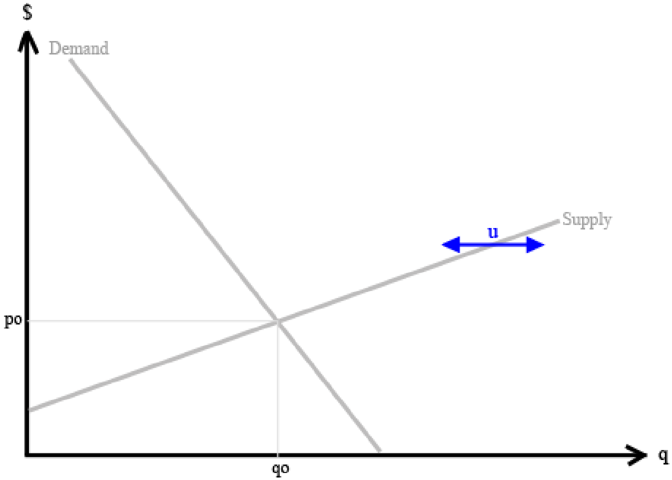

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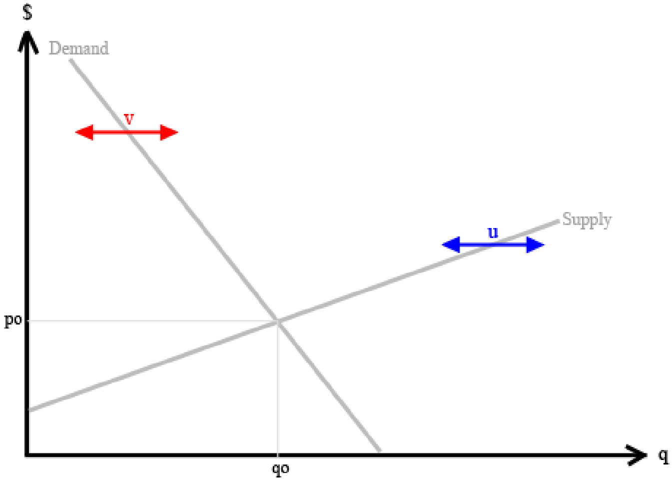

Setting the Stage

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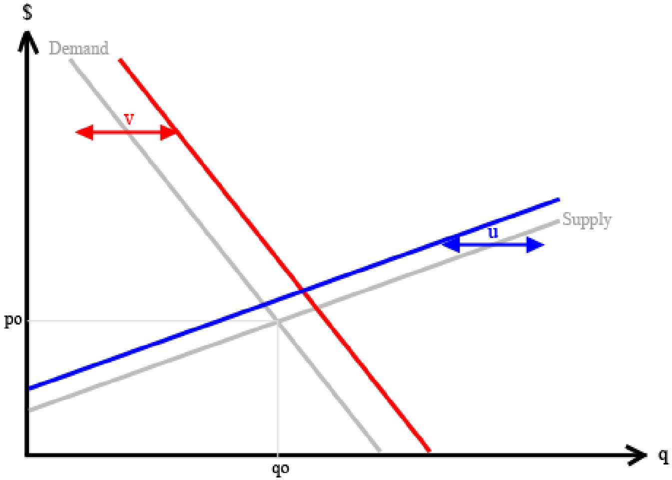

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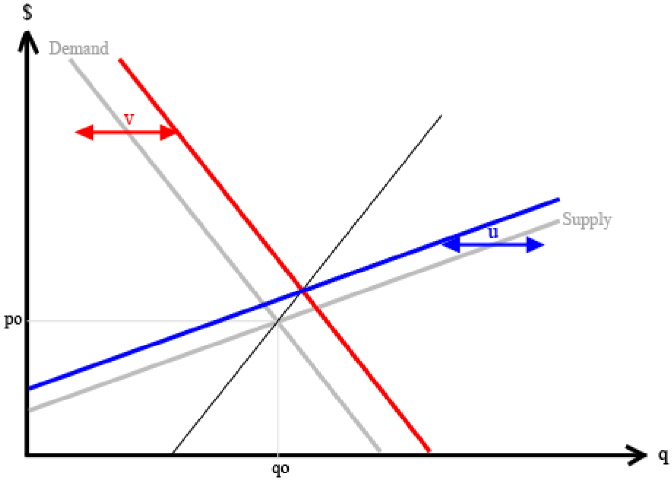

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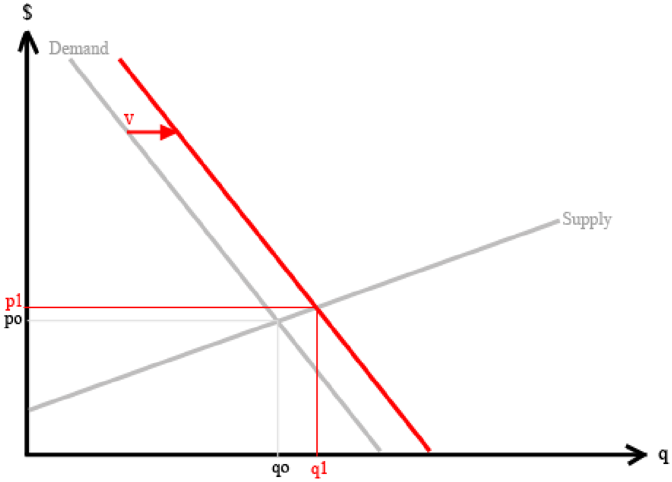

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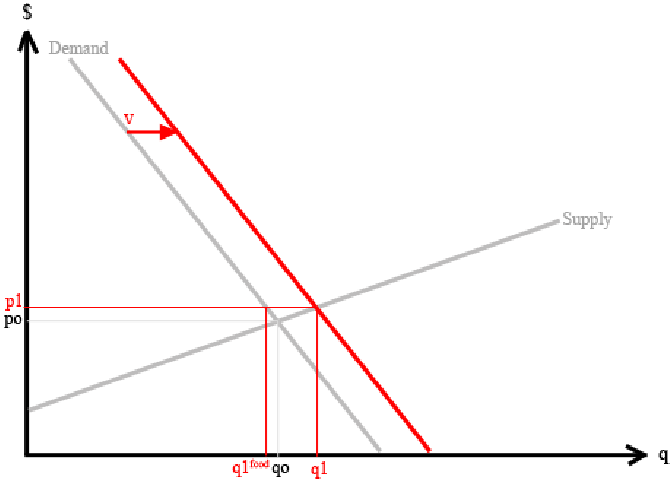

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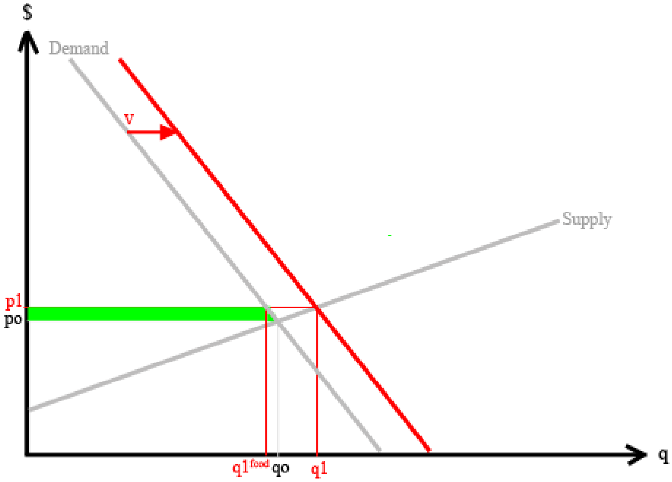

Outline

World Caloric Production and Prices

- Commodity crops form basis of food chain
  - Cassman (1999) attributes two thirds of caloric production to maize, wheat, and rice
  - Adding in soybeans brings ratio to 75%
- Conversion of production quantities into calories
  - Williamson and Williamson (1942)
- Green revolution
  - Caloric Production (4 commodities): +249% (1961-2007).
  - Growth on intensive margin (output per area)
  - Limited expansion in area

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    - Increase by 40%

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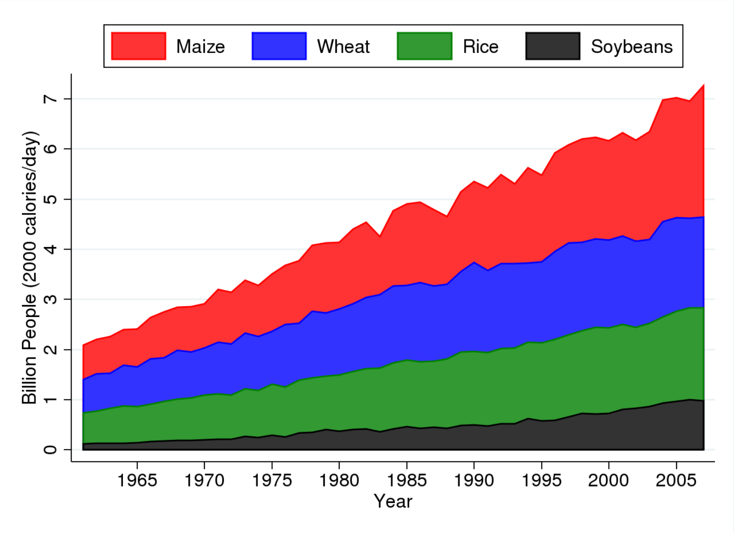

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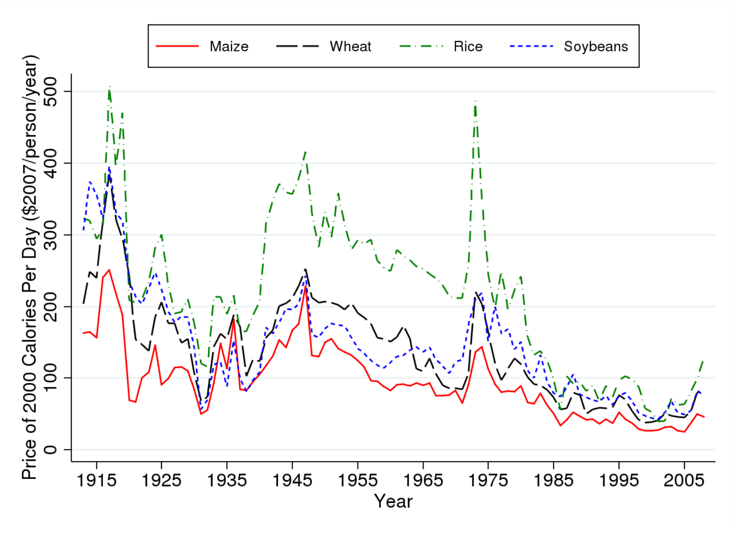

U.S. Share of Caloric Production

Country	Market Share
Maize	
United States of America	42.00
China	15.66
Brazil	5.21
USSR	3.52
Mexico	3.01
Wheat	
USSR	21.23
China	14.05
United States of America	12.07
India	8.53
Russian Federation	6.86
Soybeans	
United States of America	56.73
Brazil	14.43
China	13.05
Argentina	6.62
India	1.63

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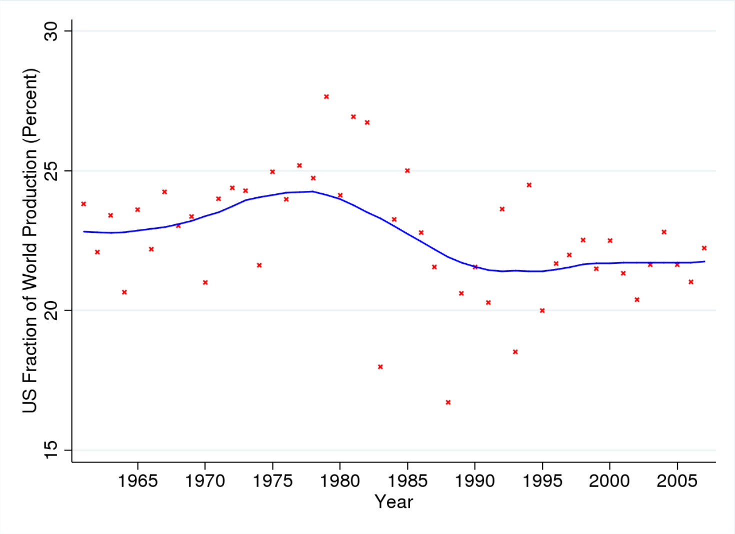

U.S. Effect on World Markets

- U.S. market share
  - calories from maize, wheat, rice, soybeans
  - roughly 23 percent
- Any policy that changes U.S. production has potential to influence world prices
- What is the influence of ethanol mandates?

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History of Biofuels

- Long history of ethanol as fuel
  - Ford's Model-T designed to run on ethanol
  - Slow phase-out of ethanol as petroleum became cheaper
- Renewed interest in ethanol to combat CO_2 emissions
  - 2005 U.S. Energy Bill: 7.5 billion gallons by 2012
  - 2007 U.S. Energy Bill: 36 billion gallons by 2022
  - 2009 Renewable Fuels Standard: 11 billion gallons in 2009
- Gasoline use: 0.39 billion gallons per day
  - 11 billion gallons: 28 days (8% of yearly demand)

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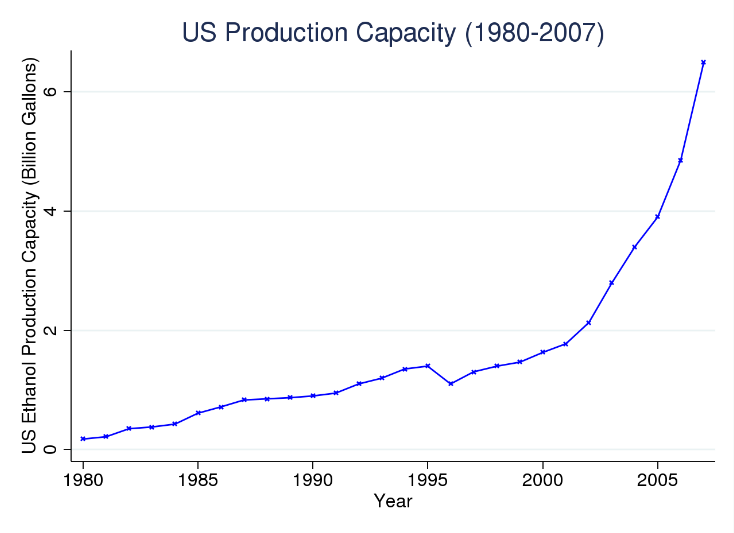

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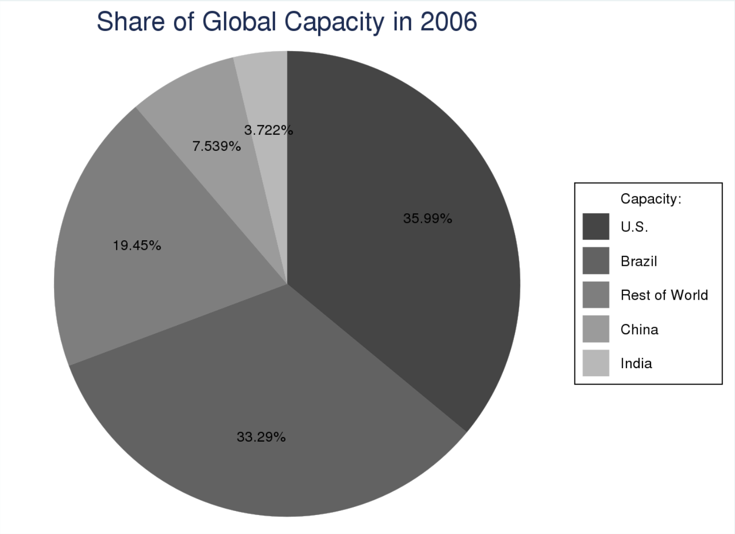

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Implications for Commodity Markets

- U.S.: Ethanol predominantly produced from maize
  - 11 billion gallons
  - Require 4.23 billion bushels of corn
    - Using 2.6 gallons per bushel average conversion
- Total U.S. maize production
  - 13 billion bushels
- Ethanol Mandate
  - One third of U.S. corn production
  - 13 percent of world maize production
  - 5 percent of world caloric production

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Storage Literature

- Competitive agricultural producers make two decisions
- Food availability is z_t
  - How much to store x_t
    - Cost of storage $\phi(x)$ convex
  - How much effort to put into new production λ_t
    - Cost of effort $g(\lambda)$ convex
- Production subject to random weather shock
  - $s_{t+1} = \lambda_t \omega_{t+1}$
- Equation of motion

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Storage Literature

- Bellman equation

$$
\begin{aligned}
v(z_t) \quad = \quad & \max_{x_t \lambda_t} \{u(z_t - x_t) - \phi(x_t) - g(\lambda_t) + \delta \mathbb{E}\left[v(z_{t+1})\right]\} \quad \text{subject to} \\
& z_{t+1} = x_t + \lambda_t \omega_{t+1} \\
& x_t \geq 0, \quad z_t - x_t \geq 0, \quad \lambda_t \geq 0
\end{aligned}
$$

- Solved by Scheinkman and Schechtman (1983) and Bobenrieth et al. (2002)
  - **(i)** consumption $c_t = z_t - x_t$ is strictly increasing in z_t
  - **(ii)** storage x_t is weakly increasing in z_t
  - **(iii)** effort λ_t is weakly decreasing in z_t

Implications of Storage Literature

- Negative weather shock in current period
  - Reduces consumption c_t
  - Increases price p_t
  - Increases price p_{t+1} (prices linked through storage)
  - Increased effort in $t+1$ (supply response)
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Model

- Estimated equations

$$
\begin{aligned}
log(s_t) &= \alpha_s + \beta_s log\left(\mathbb{E}[p_t|_{t-1}]\right) + \gamma_s \omega_t + f(t) + u_t \\
log(z_t - x_t) &= \alpha_d + \beta_d log(p_t) + g(t) + v_t
\end{aligned}
$$

s_t: production of calories at time t
$z_t - x_t$: demand for calories at time t
p_t: price of calories at time t
$log\left(\mathbb{E}(p_t|_{t-1})\right)$: futures price (delivery in t, traded in $t-1$)
ω_t: Yield shocks (weather induced) at time t
$f(t), g(t)$: time trend (technological change, population growth)
u, v: error terms

Identifying Demand

- Yield shock ω_t (rel. deviation from quadratic time trend)
  - Interacted with inverse stock levels (percent of production)
- Likely due to weather shocks
  - No autocorrelation in time series
  - No correlation across space
- Ideal instrument
  - Exogenous supply shifter
  - No direct effect on demand (trade mitigates direct impact)

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Identifying Supply

- Futures price *log* $(\mathbb{E}[p_t|_{t-1}])$ impacted through yield shocks $\omega_{t-k,k>0}$
- Storage smoothes production shocks over time
  - Speculative storage
  - Deaton & Laroque (1992,1996), Williams & Wright (1991)
- Bad weather shocks in past
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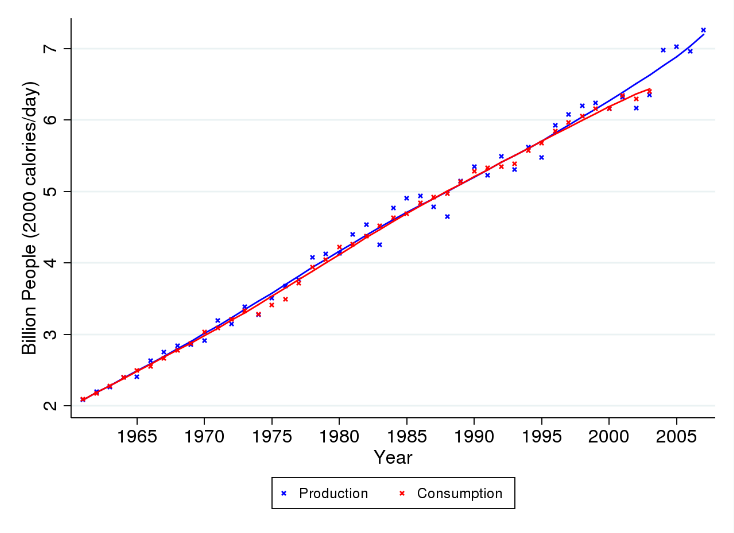

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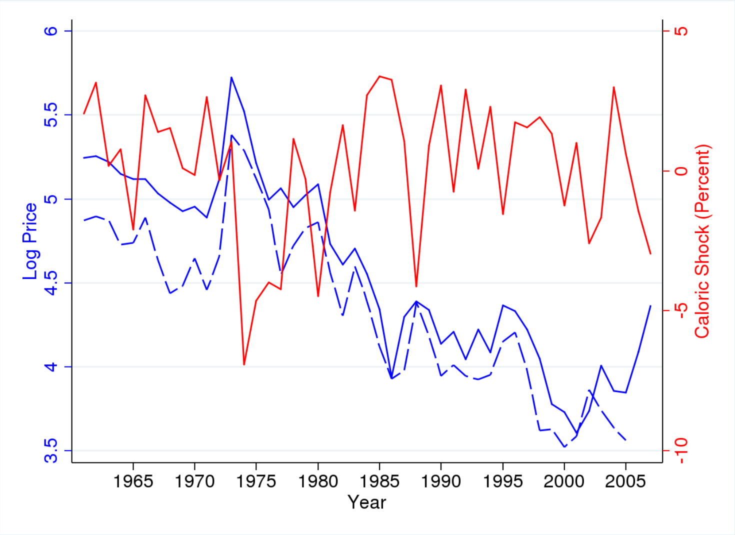

Difference to Earlier Research

- Aggregation of crops by caloric content
  - Don't confound own-price elasticity with cross-price elasticity

- Traditional Supply Estimation
  - Nerlove (1958): Regress supply on expected price
  - Our concern: expected price is endogenous
  - Instrumenting futures prices with yield shock

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Supply / Demand System

First-stage regressions:

$$
\begin{aligned}
log(p_t) &= \pi_{d0} + \sum_{k=0}^{K} \mu_{dk}\omega_{t-k} + \sum_{i=1}^{I} \rho_{di} t^i + \epsilon_{dt} \\
log\left(\mathbb{E}[p_t|_{t-1}]\right) &= \pi_{s0} + \sum_{k=0}^{K+1} \mu_{sk}\omega_{t-k} + \sum_{i=1}^{I} \rho_{si} t^i + \epsilon_{st}
\end{aligned}
$$

Supply / Demand System

Second-stage supply:

$$log(s_t) = \alpha_s + \beta_s log\left(\widehat{\mathbb{E}[p_t|_{t-1}]}\right) + \lambda_{s0}\omega_t + \underbrace{\sum_{i=1}^{I} \tau_{si} t^i}_{f(t)} + u_t$$

Stage-one variable excluded from the stage-two: $\omega_{t-k, k=1...K+1}$

Supply / Demand System

Second-stage demand:

$$log(s_t - \Delta x_t) = \alpha_d + \beta_d \widehat{log(P_t)} + \underbrace{\sum_{i=1}^{I} \tau_{di} t^i}_{g(t)} + v_t$$

Stage-one variable excluded from the stage-two: $\omega_{t-k,k=0...K}$

Outline

Data Sources

- FAO series (country-level)
  - Crops used: maize, wheat, rice, and soybeans
    - Production, area, and yield (1961-2007)
    - Change in inventories (1961-2003)
- Common unit: calories
  - Conversion using calories per unit of production
- USDA
  - Inventory levels (1961): corn, wheat, and rice

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  - Crops used: maize, wheat, rice, and soybeans
    - Production, area, and yield (1961-2007)
    - Change in inventories (1961-2003)
- Common unit: calories
  - Conversion using calories per unit of production
- USDA
  - Inventory levels (1961): corn, wheat, and rice

Data Sources - Caloric Yield Shocks

- Yield shocks
  - Baseline model: country-specific deviations from quadratic yield trends for each crop
- Countries used
  - Countries with more than 1% of world production of crop
  - Remaining countries lumped together as "Rest of World"
- Caloric Shock
  - Sum of country and crop-specific shocks
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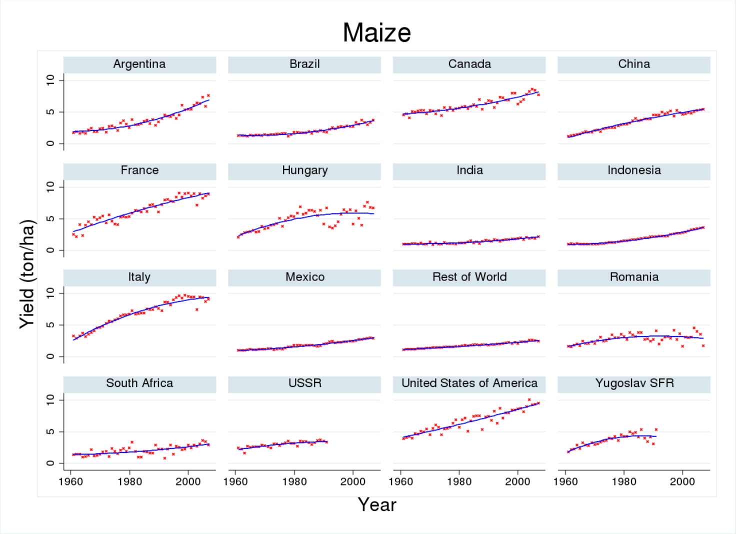
Jackknifed Residuals



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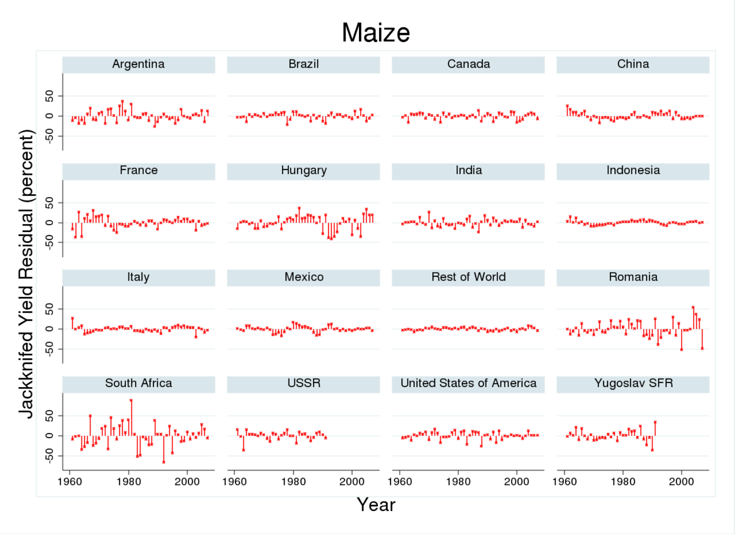
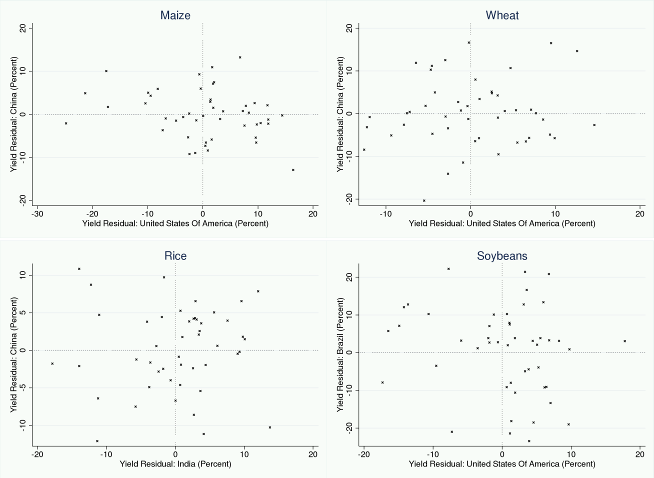


Data Sources - Weather Data

- Potential concern
  - Are yields endogenous to price?
    - Higher price could lead to higher sowing density
    - Higher price could imply shift to marginal land
  - Lack of autocorrelation in yields suggests no
  - Lack of correlation between years suggests no
- Sensitivity check
  - Country-and-crop specific yield regressions
  - US data (Schlenker and Roberts, 2009)
  - World data: NCC (6-hour time step of 1 degree grid)
- Caloric Shock
  - Attributable to deviations from average weather

Data Sources - Weather Data



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  - World data: NCC (6-hour time step of 1 degree grid)
    - Average over agricultural area
- Caloric Shock
  - Attributable to deviations from average weather

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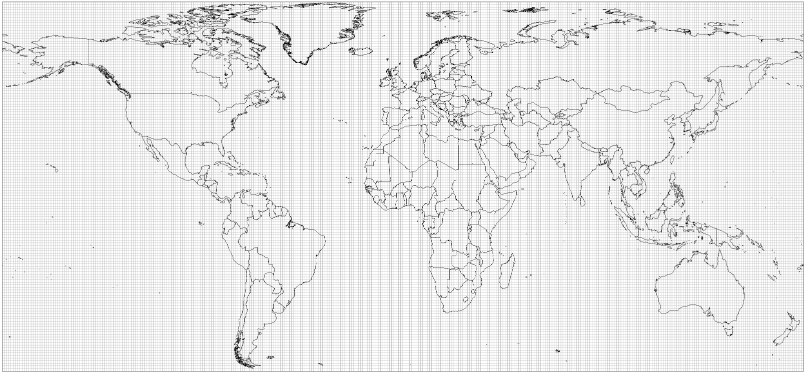
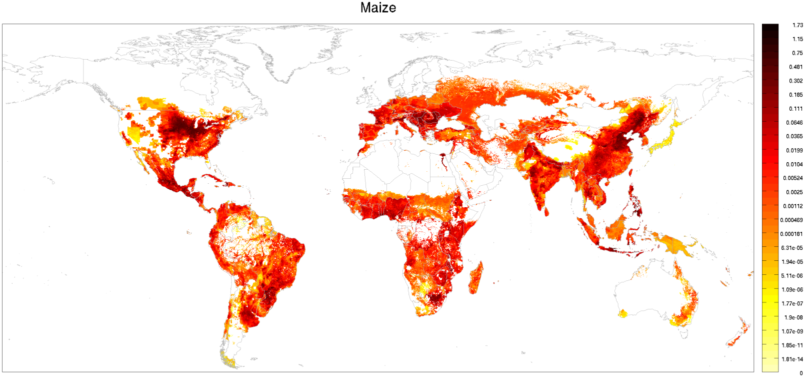
Growing Areas

NCC grid system



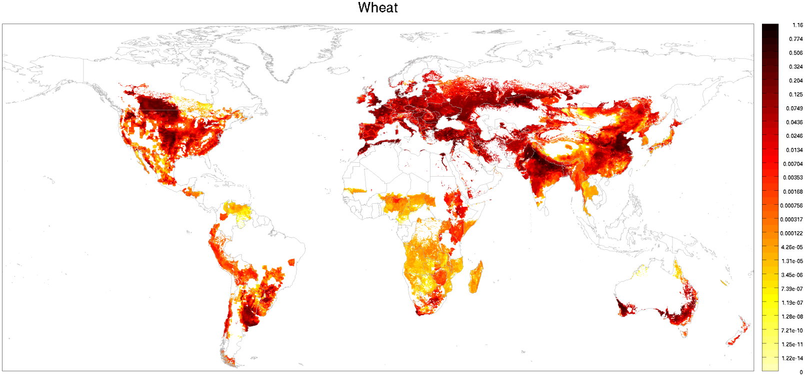
Growing Areas

Maize: Growing Area (Fraction of Grid)

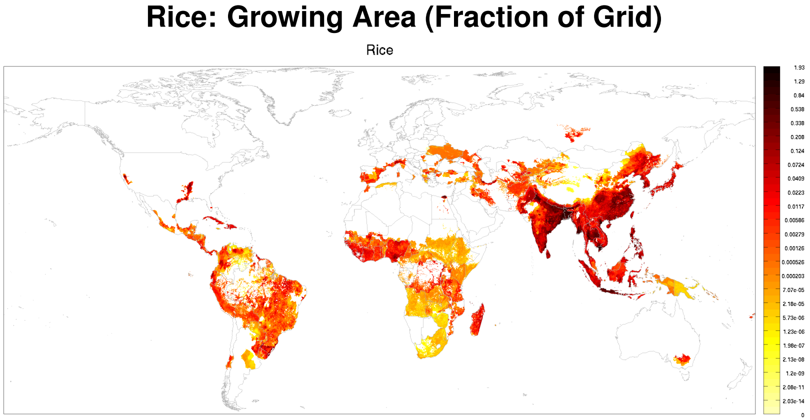


Growing Areas

Wheat: Growing Area (Fraction of Grid)

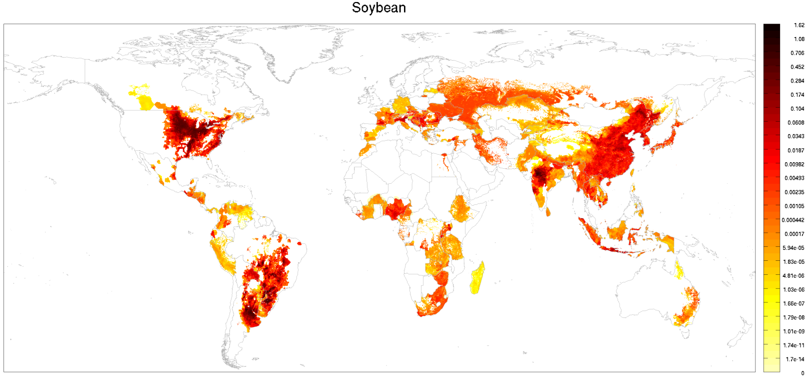


Growing Areas



Growing Areas

Soybeans: Growing Area (Fraction of Grid)



Data Sources - Prices

- Long time series
  - Crop prices in US in December of each year
    - 1915-2008
- Futures prices
  - Chicago Board of trade: September delivery
  - p_t: average price in September of delivery
  - $log(\mathbb{E}[p_t|_{t-1}])$: average price in October of previous year
  - Only available for maize, soybeans, and wheat
- Price per calory
  - Converted using calory per unit of production
  - Deflated using CPI

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  - Converted using calory per unit of production
  - Deflated using CPI

Descriptive Statistics

Variable	Unit	Mean	Std. Dev.	Min	Max
Year		1982	12.56	1961	2003
Caloric Production	billion people	4.32	1.34	2.08	6.35
Caloric Storage	million people	15.9	118	-317	210
Caloric Stock	million people	982	339	445	1564
Caloric Shock (Linear Trend)	million people	2.97	104	-226	175
Caloric Shock (Quadratic Trend)	million people	4.67	107	-240	159
Caloric Shock (Weather Linear)	million people	-2.22	90	-310	128
Caloric Shock (Weather Quadratic)	million people	2.47	64	-162	94
Caloric Price (Futures Delivery)	US$2007 per year	89.57	43.28	33.88	217.28
Caloric Price (Futures Prev. Year)	US$2007 per year	89.13	39.34	37.96	208.15
Caloric Price (Dec. USDA Prices)	US$2007 per year	117.29	60.95	36.85	305.76

Outline

Regression Results - Demand

	Model					
	2SLS	**3SLS**	**2SLS**	**3SLS**	**2SLS**	**3SLS**
Demand Elas.	-0.0473***					
(s.e.)	(0.0176)					
Supply Elas.						
(s.e.)						
Price Inc.						
95% Int.						
	Demand					
Price p_t	-4.73e-02***					
	(1.76e-02)					
Time Trend	4.26e-02***					
	(9.02e-04)					
Time Trend^2	-4.17e-04***					
	(2.40e-05)					
Time Trend^3						
Observations	41					
Time Trend I	2					
Shock Lags K	1					

Regression Results - Demand

	Model					
	2SLS	3SLS	2SLS	3SLS	2SLS	3SLS
Demand Elas.	-0.0473***	-0.0449***				
(s.e.)	(0.0176)	(0.0165)				
Supply Elas.						
(s.e.)						
Price Inc.						
95% Int.						
			Demand			
Price p_t	-4.73e-02***	-4.49e-02***				
	(1.76e-02)	(1.65e-02)				
Time Trend	4.26e-02***	4.26e-02***				
	(9.02e-04)	(9.39e-04)				
Time Trend^2	-4.17e-04***	-4.15e-04***				
	(2.40e-05)	(2.42e-05)				
Time Trend^3						
Observations	41	41				
Time Trend I	2	2				
Shock Lags K	1	1				

Regression Results - Demand

	Model					
	2SLS	**3SLS**	**2SLS**	**3SLS**	**2SLS**	**3SLS**
Demand Elas.	-0.0473***	-0.0449***	-0.0635***	-0.0595***		
(s.e.)	(0.0176)	(0.0165)	(0.0231)	(0.0217)		
Supply Elas.						
(s.e.)						
Price Inc.						
95% Int.						
			Demand			
Price p_t	-4.73e-02***	-4.49e-02***	-6.35e-02***	-5.95e-02***		
	(1.76e-02)	(1.65e-02)	(2.31e-02)	(2.17e-02)		
Time Trend	4.26e-02***	4.26e-02***	4.65e-02***	4.71e-02***		
	(9.02e-04)	(9.39e-04)	(2.97e-03)	(3.35e-03)		
Time Trend^2	-4.17e-04***	-4.15e-04***	-6.51e-04***	-6.73e-04***		
	(2.40e-05)	(2.42e-05)	(1.72e-04)	(1.87e-04)		
Time Trend^3			3.44e-06	3.75e-06		
			(2.50e-06)	(2.66e-06)		
Observations	41	41	41	41		
Time Trend I	2	2	3	3		
Shock Lags K	1	1	1	1		

Regression Results - Demand

	Model					
	2SLS	3SLS	2SLS	3SLS	2SLS	3SLS
Demand Elas.	-0.0473***	-0.0449***	-0.0635***	-0.0595***	-0.0624***	-0.0654***
(s.e.)	(0.0176)	(0.0165)	(0.0231)	(0.0217)	(0.0233)	(0.0234)
Supply Elas.						
(s.e.)						
Price Inc.						
95% Int.						
			Demand			
Price p_t	-4.73e-02***	-4.49e-02***	-6.35e-02***	-5.95e-02***	-6.24e-02***	-6.54e-02**
	(1.76e-02)	(1.65e-02)	(2.31e-02)	(2.17e-02)	(2.33e-02)	(2.34e-02)
Time Trend	4.26e-02***	4.26e-02***	4.65e-02***	4.71e-02***	4.74e-02***	4.91e-02**
	(9.02e-04)	(9.39e-04)	(2.97e-03)	(3.35e-03)	(3.59e-03)	(4.24e-03)
Time Trend^2	-4.17e-04***	-4.15e-04***	-6.51e-04***	-6.73e-04***	-6.89e-04***	-7.72e-04**
	(2.40e-05)	(2.42e-05)	(1.72e-04)	(1.87e-04)	(2.00e-04)	(2.28e-04)
Time Trend^3			3.44e-06	3.75e-06	3.96e-06	5.06e-06
			(2.50e-06)	(2.66e-06)	(2.85e-06)	(3.18e-06)
Observations	41	41	41	41	40	40
Time Trend I	2	2	3	3	3	3
Shock Lags K	1	1	1	1	2	2

Regression Results - Supply

	Model					
	2SLS	3SLS	2SLS	3SLS	2SLS	3SLS
Demand Elas.	-0.0473***	-0.0449***	-0.0635***	-0.0595***	-0.0624***	-0.0654***
(s.e.)	(0.0176)	(0.0165)	(0.0231)	(0.0217)	(0.0233)	(0.0234)
Supply Elas.	0.1157***					
(s.e.)	(0.0220)					
Price Inc.						
95% Int.						
Supply						
$\mathbb{E}[p_t \mid_{t-1}]$	1.16e-01***					
	(2.20e-02)					
Shock ω_t	2.59e-01***					
	(2.95e-02)					
Time Trend	4.34e-02***					
	(8.87e-04)					
Time Trend^2	-3.31e-04***					
	(2.53e-05)					
Time Trend^3						
Observations	41					
Time Trend I	2					
Shock Lags K	1					

Regression Results - Supply

	Model					
	2SLS	3SLS	2SLS	3SLS	2SLS	3SLS
Demand Elas.	-0.0473***	-0.0449***	-0.0635***	-0.0595***	-0.0624***	-0.0654***
(s.e.)	(0.0176)	(0.0165)	(0.0231)	(0.0217)	(0.0233)	(0.0234)
Supply Elas.	0.1157***					
(s.e.)	(0.0220)					
Price Inc.	31.69					
95% Int.	(22.90,46.41)					
	Supply					
$\mathbb{E}[p_t\|_{t-1}]$	1.16e-01***					
	(2.20e-02)					
Shock ω_t	2.59e-01***					
	(2.95e-02)					
Time Trend	4.34e-02***					
	(8.87e-04)					
Time Trend^2	-3.31e-04***					
	(2.53e-05)					
Time Trend^3						
Observations	41					
Time Trend I	2					
Shock Lags K	1					

Regression Results - Supply

	Model					
	2SLS	3SLS	2SLS	3SLS	2SLS	3SLS
Demand Elas.	-0.0473***	-0.0449***	-0.0635***	-0.0595***	-0.0624***	-0.0654***
(s.e.)	(0.0176)	(0.0165)	(0.0231)	(0.0217)	(0.0233)	(0.0234)
Supply Elas.	0.1157***	0.1160***				
(s.e.)	(0.0220)	(0.0200)				
Price Inc.	31.69	31.89				
95% Int.	(22.90,46.41)	(23.82,44.67)				
			Supply			
$\mathbb{E}[p_t\|_{t-1}]$	1.16e-01***	1.16e-01***				
	(2.20e-02)	(2.00e-02)				
Shock ω_t	2.59e-01***	2.58e-01***				
	(2.95e-02)	(2.69e-02)				
Time Trend	4.34e-02***	4.34e-02***				
	(8.87e-04)	(8.31e-04)				
Time Trend^2	-3.31e-04***	-3.30e-04***				
	(2.53e-05)	(2.34e-05)				
Time Trend^3						
Observations	41	41				
Time Trend I	2	2				
Shock Lags K	1	1				

Regression Results - Supply

	Model					
	2SLS	3SLS	2SLS	3SLS	2SLS	3SLS
Demand Elas.	-0.0473***	-0.0449***	-0.0635***	-0.0595***	-0.0624***	-0.0654***
(s.e.)	(0.0176)	(0.0165)	(0.0231)	(0.0217)	(0.0233)	(0.0234)
Supply Elas.	0.1157***	0.1160***	0.0864***	0.0881***		
(s.e.)	(0.0220)	(0.0200)	(0.0183)	(0.0167)		
Price Inc.	31.69	31.89	34.82	35.18		
95% Int.	(22.90,46.41)	(23.82,44.67)	(24.07,54.24)	(24.87,53.10)		
			Supply			
$\mathbb{E}[p_t\|_{t-1}]$	1.16e-01***	1.16e-01***	8.64e-02***	8.81e-02***		
	(2.20e-02)	(2.00e-02)	(1.83e-02)	(1.67e-02)		
Shock ω_t	2.59e-01***	2.58e-01***	2.67e-01***	2.67e-01***		
	(2.95e-02)	(2.69e-02)	(2.41e-02)	(2.22e-02)		
Time Trend	4.34e-02***	4.34e-02***	5.27e-02***	5.27e-02***		
	(8.87e-04)	(8.31e-04)	(2.23e-03)	(2.06e-03)		
Time Trend^2	-3.31e-04***	-3.30e-04***	-8.59e-04***	-8.54e-04***		
	(2.53e-05)	(2.34e-05)	(1.20e-04)	(1.11e-04)		
Time Trend^3			7.64e-06***	7.59e-06***		
			(1.74e-06)	(1.61e-06)		
Observations	41	41	41	41		
Time Trend I	2	2	3	3		
Shock Lags K	1	1	1	1		

Regression Results - Supply

	Model					
	2SLS	**3SLS**	**2SLS**	**3SLS**	**2SLS**	**3SLS**
Demand Elas.	-0.0473***	-0.0449***	-0.0635***	-0.0595***	-0.0624***	-0.0654***
(s.e.)	(0.0176)	(0.0165)	(0.0231)	(0.0217)	(0.0233)	(0.0234)
Supply Elas.	0.1157***	0.1160***	0.0864***	0.0881***	0.0871***	0.0864***
(s.e.)	(0.0220)	(0.0200)	(0.0183)	(0.0167)	(0.0185)	(0.0171)
Price Inc.	31.69	31.89	34.82	35.18	34.99	34.27
95% Int.	(22.90,46.41)	(23.82,44.67)	(24.07,54.24)	(24.87,53.10)	(24.04,54.95)	(24.02,52.3
			Supply			
$\mathbb{E}[p_t\|_{t-1}]$	1.16e-01***	1.16e-01***	8.64e-02***	8.81e-02***	8.71e-02***	8.64e-02**
	(2.20e-02)	(2.00e-02)	(1.83e-02)	(1.67e-02)	(1.85e-02)	(1.71e-02)
Shock ω_t	2.59e-01***	2.58e-01***	2.67e-01***	2.67e-01***	2.68e-01***	2.68e-01**
	(2.95e-02)	(2.69e-02)	(2.41e-02)	(2.22e-02)	(2.41e-02)	(2.22e-02)
Time Trend	4.34e-02***	4.34e-02***	5.27e-02***	5.27e-02***	5.32e-02***	5.33e-02**
	(8.87e-04)	(8.31e-04)	(2.23e-03)	(2.06e-03)	(2.70e-03)	(2.49e-03)
Time Trend^2	-3.31e-04***	-3.30e-04***	-8.59e-04***	-8.54e-04***	-8.81e-04***	-8.82e-04**
	(2.53e-05)	(2.34e-05)	(1.20e-04)	(1.11e-04)	(1.41e-04)	(1.30e-04)
Time Trend^3			7.64e-06***	7.59e-06***	7.95e-06***	7.96e-06**
			(1.74e-06)	(1.61e-06)	(1.99e-06)	(1.84e-06)
Observations	41	41	41	41	40	40
Time Trend I	2	2	3	3	3	3
Shock Lags K	1	1	1	1	2	2

Regression Results - First Stage

	Model					
	2SLS	3SLS	2SLS	3SLS	2SLS	3SLS
			Demand			
Shock ω_t	-1.02e+00***	-1.15e+00***	-1.01e+00***	-1.09e+00***	-1.03e+00***	-1.01e+0
	(2.84e-01)	(2.48e-01)	(3.10e-01)	(2.62e-01)	(3.14e-01)	(2.67e-
Shock ω_{t-1}	-5.57e-01*	-4.39e-01*	-5.48e-01*	-4.25e-01*	-5.24e-01*	-4.04e-
	(2.89e-01)	(2.26e-01)	(3.07e-01)	(2.20e-01)	(3.14e-01)	(2.23e-
Shock ω_{t-2}					1.60e-01	-1.07e-
					(3.16e-01)	(1.99e-
Time Trend	-9.97e-03	-4.86e-03	-6.76e-03	1.39e-02	1.86e-02	3.04e-
	(1.10e-02)	(1.11e-02)	(3.35e-02)	(3.47e-02)	(3.96e-02)	(4.01e-
Time Trend^2	-5.04e-04**	-6.04e-04**	-6.85e-04	-1.63e-03	-1.85e-03	-2.39e-
	(2.49e-04)	(2.45e-04)	(1.80e-03)	(1.81e-03)	(2.04e-03)	(2.02e-
Time Trend^3			2.75e-06	1.55e-05	1.83e-05	2.59e-
			(2.71e-05)	(2.68e-05)	(3.01e-05)	(2.94e-
Observations	41	41	41	41	40	40
Time Trend I	2	2	3	3	3	3
Shock Lags K	1	1	1	1	2	2

Regression Results - First Stage

	Model					
	2SLS	3SLS	2SLS	3SLS	2SLS	3SLS
			Supply			
Shock ω_{t-1}	-8.93e-01***	-8.45e-01***	-9.31e-01***	-9.56e-01***	-9.26e-01***	-9.37e-01**
	(2.16e-01)	(1.97e-01)	(2.28e-01)	(2.04e-01)	(2.34e-01)	(2.07e-01)
Shock ω_{t-2}	-3.13e-01	-3.81e-01*	-3.38e-01	-2.70e-01	-3.05e-01	-2.82e-01
	(2.23e-01)	(1.97e-01)	(2.29e-01)	(1.93e-01)	(2.36e-01)	(2.06e-01)
Shock ω_{t-3}					-7.35e-02	-7.68e-02
					(2.37e-01)	(1.98e-01)
Shock ω_t	-6.18e-01***	-6.22e-01***	-6.58e-01***	-6.76e-01***	-6.33e-01**	-6.42e-01**
	(2.15e-01)	(1.98e-01)	(2.28e-01)	(2.07e-01)	(2.39e-01)	(2.12e-01)
Time Trend	-7.13e-03	-7.59e-03	-2.27e-02	-2.18e-02	-9.08e-03	-9.19e-03
	(8.95e-03)	(8.25e-03)	(2.87e-02)	(2.61e-02)	(3.51e-02)	(3.12e-02)
Time Trend^2	-5.04e-04**	-4.92e-04***	3.37e-04	3.06e-04	-2.85e-04	-2.75e-04
	(2.00e-04)	(1.84e-04)	(1.48e-03)	(1.35e-03)	(1.75e-03)	(1.56e-03)
Time Trend^3			-1.25e-05	-1.22e-05	-4.07e-06	-4.26e-06
			(2.18e-05)	(1.98e-05)	(2.51e-05)	(2.24e-05)
Observations	41	41	41	41	40	40
Time Trend I	2	2	3	3	3	3
Shock Lags K	1	1	1	1	2	2

Sensitivity Check - Yield Deviations

- Jackknifed Yield Residuals
  - Check: Linear instead of quadratic trend
- Production trend
  - Check: Linear instead of quadratic trend

Sensitivity Check - Yield Deviations

	Model					
	2SLS	3SLS	2SLS	3SLS	2SLS	3SLS
Panel A: Baseline						
Demand Elas.	-0.0473***	-0.0449***	-0.0635***	-0.0595***	-0.0624***	-0.0654***
(s.e.)	(0.0176)	(0.0165)	(0.0231)	(0.0217)	(0.0233)	(0.0234)
Supply Elas.	0.1157***	0.1160***	0.0864***	0.0881***	0.0871***	0.0864***
(s.e.)	(0.0220)	(0.0200)	(0.0183)	(0.0167)	(0.0185)	(0.0171)
Price Inc.	31.69	31.89	34.82	35.18	34.99	34.27
95% Int.	(22.90,46.41)	(23.82,44.67)	(24.07,54.24)	(24.87,53.10)	(24.04,54.95)	(24.02,52.35)
Panel B: Caloric Shock Derived using Linear Time Trend						
Demand Elas.	-0.0461**	-0.0424**	-0.0585**	-0.0533**	-0.0573**	-0.0626***
(s.e.)	(0.0177)	(0.0166)	(0.0224)	(0.0210)	(0.0228)	(0.0232)
Supply Elas.	0.1080***	0.1085***	0.0908***	0.0929***	0.0905***	0.0899***
(s.e.)	(0.0213)	(0.0191)	(0.0202)	(0.0182)	(0.0206)	(0.0189)
Price Inc.	33.60	34.09	35.06	35.57	35.56	34.16
95% Int.	(23.97,50.10)	(25.20,48.41)	(23.99,55.41)	(24.99,54.19)	(24.04,57.13)	(23.81,52.59)
Observations	41	41	41	41	40	40
Time Trend I	2	2	3	3	3	3
Shock Lags K	1	1	1	1	2	2

Sensitivity Check - Yield Deviations

- Caloric shock is product of
  - Jackknifed yield residuals
  - Area harvested
  - Caloric conversion (calories per unit of output)
- Check:
  - Predicted area (quadratic trend) instead of actual

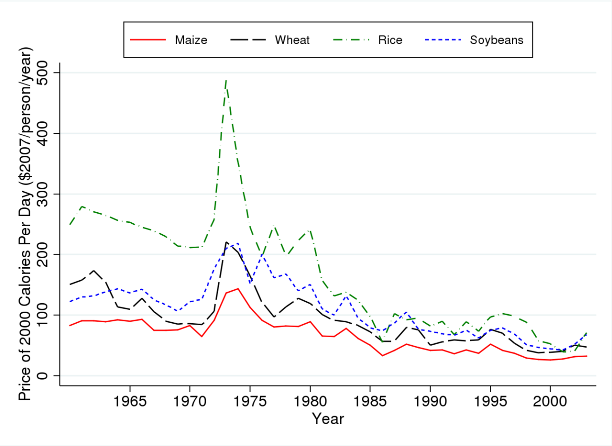
Sensitivity Check - Yield Deviations

	Model					
	2SLS	**3SLS**	**2SLS**	**3SLS**	**2SLS**	**3SLS**
			Panel A: Baseline			
Demand Elas.	-0.0473***	-0.0449***	-0.0635***	-0.0595***	-0.0624***	-0.0654***
(s.e.)	(0.0176)	(0.0165)	(0.0231)	(0.0217)	(0.0233)	(0.0234)
Supply Elas.	0.1157***	0.1160***	0.0864***	0.0881***	0.0871***	0.0864***
(s.e.)	(0.0220)	(0.0200)	(0.0183)	(0.0167)	(0.0185)	(0.0171)
Price Inc.	31.69	31.89	34.82	35.18	34.99	34.27
95% Int.	(22.90,46.41)	(23.82,44.67)	(24.07,54.24)	(24.87,53.10)	(24.04,54.95)	(24.02,52.35)
			Panel C: Caloric Shock Derived using Quadratic Area Trend			
Demand Elas.	-0.0459***	-0.0429***	-0.0610***	-0.0557***	-0.0593**	-0.0627***
(s.e.)	(0.0174)	(0.0161)	(0.0224)	(0.0208)	(0.0225)	(0.0226)
Supply Elas.	0.1159***	0.1158***	0.0892***	0.0908***	0.0897***	0.0892***
(s.e.)	(0.0211)	(0.0190)	(0.0176)	(0.0160)	(0.0178)	(0.0163)
Price Inc.	31.88	32.27	34.65	35.32	34.99	34.09
95% Int.	(23.21,46.21)	(24.31,44.71)	(24.26,53.01)	(25.34,52.25)	(24.36,53.95)	(24.32,50.83)
Observations	41	41	41	41	40	40
Time Trend I	2	2	3	3	3	3
Shock Lags K	1	1	1	1	2	2

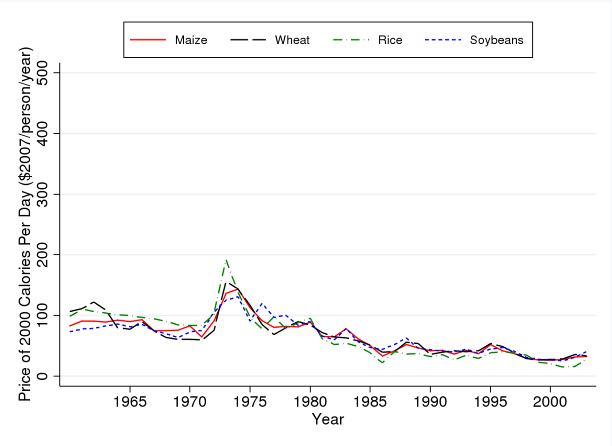
Sensitivity Check - Yield Deviations

- Caloric conversion factors
  - Given in Williamson and Williamson (1942)
- Check:
  - Ratio of caloric conversion factors equals ratio of averages prices

Sensitivity Check - Yield Deviations



Sensitivity Check - Yield Deviations



Sensitivity Check - Yield Deviations

	Model					
	2SLS	3SLS	2SLS	3SLS	2SLS	3SLS
Panel A: Baseline						
Demand Elas.	-0.0473***	-0.0449***	-0.0635***	-0.0595***	-0.0624***	-0.0654***
(s.e.)	(0.0176)	(0.0165)	(0.0231)	(0.0217)	(0.0233)	(0.0234)
Supply Elas.	0.1157***	0.1160***	0.0864***	0.0881***	0.0871***	0.0864***
(s.e.)	(0.0220)	(0.0200)	(0.0183)	(0.0167)	(0.0185)	(0.0171)
Price Inc.	31.69	31.89	34.82	35.18	34.99	34.27
95% Int.	(22.90,46.41)	(23.82,44.67)	(24.07,54.24)	(24.87,53.10)	(24.04,54.95)	(24.02,52.35)
Panel D: Rescaled Caloric Conversion Factors to Equalize Average Prices						
Demand Elas.	-0.0517***	-0.0536***	-0.0613***	-0.0592***	-0.0601***	-0.0744***
(s.e.)	(0.0165)	(0.0156)	(0.0194)	(0.0190)	(0.0203)	(0.0200)
Supply Elas.	0.1213***	0.1175***	0.0750***	0.0740***	0.0788***	0.0764***
(s.e.)	(0.0279)	(0.0256)	(0.0139)	(0.0126)	(0.0145)	(0.0133)
Price Inc.	30.04	30.23	37.93	38.73	37.28	34.05
95% Int.	(21.13,45.64)	(21.73,44.57)	(27.30,55.87)	(28.17,56.22)	(26.60,55.55)	(25.30,48.05)
Observations	41	41	41	41	40	40
Time Trend I	2	2	3	3	3	3
Shock Lags K	1	1	1	1	2	2

Sensitivity Check - Yield Deviations

- Shock ω_t
  - Ratio of relative caloric shock to relative inventory level
- Check:
  - Do not normalize by inventory level

Sensitivity Check - Yield Deviations

	Model					
	2SLS	3SLS	2SLS	3SLS	2SLS	3SLS
			Panel A: Baseline			
Demand Elas.	-0.0473***	-0.0449***	-0.0635***	-0.0595***	-0.0624***	-0.0654***
(s.e.)	(0.0176)	(0.0165)	(0.0231)	(0.0217)	(0.0233)	(0.0234)
Supply Elas.	0.1157***	0.1160***	0.0864***	0.0881***	0.0871***	0.0864***
(s.e.)	(0.0220)	(0.0200)	(0.0183)	(0.0167)	(0.0185)	(0.0171)
Price Inc.	31.69	31.89	34.82	35.18	34.99	34.27
95% Int.	(22.90,46.41)	(23.82,44.67)	(24.07,54.24)	(24.87,53.10)	(24.04,54.95)	(24.02,52.35)
			Panel E: Caloric Shock not Divided by Inventory			
Demand Elas.	-0.0400**	-0.0381**	-0.0534**	-0.0494**	-0.0529**	-0.0533**
(s.e.)	(0.0165)	(0.0154)	(0.0208)	(0.0196)	(0.0211)	(0.0209)
Supply Elas.	0.1195***	0.1193***	0.0913***	0.0941***	0.0932***	0.0918***
(s.e.)	(0.0211)	(0.0183)	(0.0173)	(0.0151)	(0.0175)	(0.0156)
Price Inc.	32.31	32.45	35.92	35.89	35.59	35.58
95% Int.	(23.57,46.71)	(24.86,43.99)	(25.28,54.58)	(26.32,51.56)	(25.02,54.14)	(25.82,51.83)
Observations	41	41	41	41	40	40
Time Trend I	2	2	3	3	3	3
Shock Lags K	1	1	1	1	2	2

Sensitivity Check - Weather Shocks

- Caloric shocks
  - Deviations from yield trend
- Check
  - Yield shocks that are attributable to weather shocks

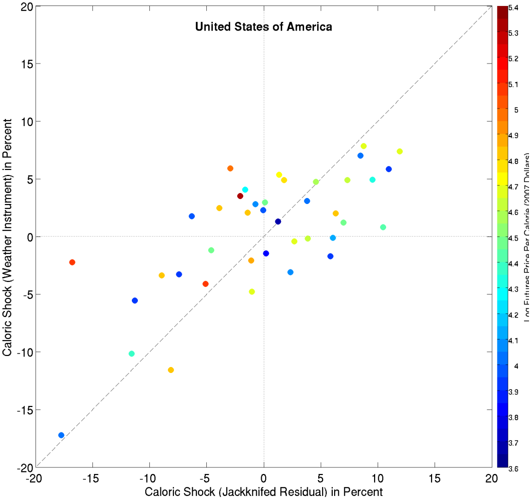
Sensitivity Check - Weather Shocks

	Model				
	2SLS	3SLS	2SLS	3SLS	2SLS
	Panel A: Baseline				
Demand Elas.	-0.0473***	-0.0449***	-0.0635***	-0.0595***	-0.0624***
(s.e.)	(0.0176)	(0.0165)	(0.0231)	(0.0217)	(0.0233)
Supply Elas.	0.1157***	0.1160***	0.0864***	0.0881***	0.0871***
(s.e.)	(0.0220)	(0.0200)	(0.0183)	(0.0167)	(0.0185)
Price Inc.	31.69	31.89	34.82	35.18	34.99
95% Int.	(22.90,46.41)	(23.82,44.67)	(24.07,54.24)	(24.87,53.10)	(24.04,54.95)
	Panel B: Production Shock Derived using Observed Weather				
Demand Elas.	-0.1658	-0.0274	-0.0598	-0.0201	-0.0191
(s.e.)	(0.4156)	(0.0349)	(0.1815)	(0.0320)	(0.0343)
Supply Elas.	0.1477	0.3320	-0.0453	-0.0236	-0.0391
(s.e.)	(0.3425)	(0.2592)	(0.2054)	(0.1879)	(0.0791)
Price Inc.	-2.99	30.12	-16.48	69.75	23.61
95% Int.	(-123.27,128.89)	(-95.68,124.45)	(-291.44,290.35)	(-431.72,434.53)	(-905.27,891.40)
Observations	38	38	38	38	37
Time Trend I	2	2	3	3	3
Shock Lags K	1	1	1	1	2

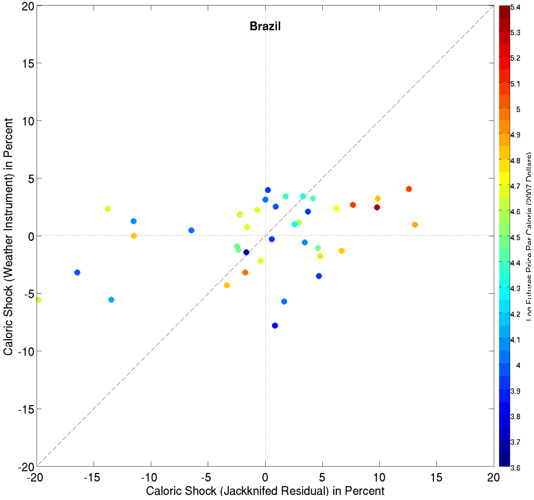
Sensitivity Check - Weather Shocks

- Weak instruments and decrease significance levels
  - Likely due to data problems
- Correlation between two yield shocks
  - Deviations from trend
  - Attributable to weather
- US (good daily data): 0.71
- Rest of world not as good

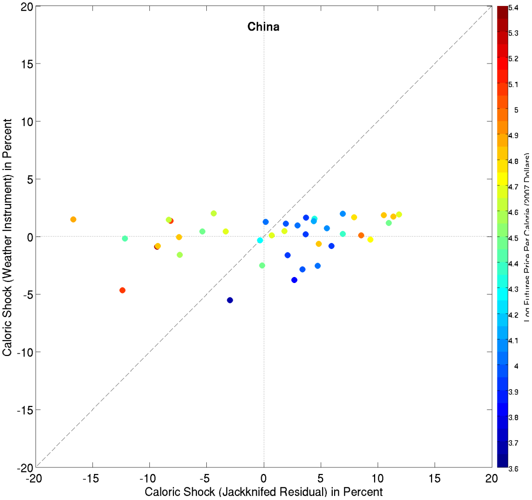
Sensitivity Check - Weather Shocks



Sensitivity Check - Weather Shocks



Sensitivity Check - Weather Shocks



Contrast to Other Approaches

	SUR - Price Not Instrumented		Demand Instrumented / Supply Not Instrumented
	(1)	(2)	
Demand Elas.	-0.0166*	-0.0177*	
(s.e.)	(0.0091)	(0.0095)	
Supply Elas.	0.0155	0.0140	
(s.e.)	(0.0172)	(0.0152)	
Price Inc.	168.77	82.84	
95% Conf. Int.	(-654,1151)	(-531,1109)	
Time Trend I	2	3	
Shocks K	n.A.	n.A.	
Supply Lags	n.A.	n.A.	

Contrast to Other Approaches

	SUR - Price Not Instrumented		Demand Instrumented / Supply Not Instrumented			
	(1)	(2)	(3)	(4)	(5)	(6)
Demand Elas.	-0.0166*	-0.0177*	-0.0473***			
(s.e.)	(0.0091)	(0.0095)	(0.0176)			
Supply Elas.	0.0155	0.0140	0.0289			
(s.e.)	(0.0172)	(0.0152)	(0.0225)			
Price Inc.	168.77	82.84	81.09			
95% Int.	(-654,1151)	(-531,1109)	(37,229)			
Time Trend I	2	3	2			
Shocks K	n.A.	n.A.	1			
Supply Lags	n.A.	n.A.	none			

Contrast to Other Approaches

	SUR - Price Not Instrumented		Demand Instrumented / Supply Not Instrumented			
	(1)	(2)	(3)	(4)	(5)	(6)
Demand Elas.	-0.0166*	-0.0177*	-0.0473***	-0.0473***		
(s.e.)	(0.0091)	(0.0095)	(0.0176)	(0.0176)		
Supply Elas.	0.0155	0.0140	0.0289	0.0311		
(s.e.)	(0.0172)	(0.0152)	(0.0225)	(0.0236)		
Price Inc.	168.77	82.84	81.09	73.82		
95% Int.	(-654,1151)	(-531,1109)	(37,229)	(36,223)		
Time Trend I	2	3	2	2	2	
Shocks K	n.A.	n.A.	1	1	1	
Supply Lags	n.A.	n.A.	0	1	2	

Contrast to Other Approaches

	SUR - Price Not Instrumented		Demand Instrumented / Supply Not Instrumented			
	(1)	(2)	(3)	(4)	(5)	(6)
Demand Elas.	-0.0166*	-0.0177*	-0.0473***	-0.0473***	-0.0473***	-0.0624***
(s.e.)	(0.0091)	(0.0095)	(0.0176)	(0.0176)	(0.0176)	(0.0233)
Supply Elas.	0.0155	0.0140	0.0289	0.0311	0.0310	0.0289
(s.e.)	(0.0172)	(0.0152)	(0.0225)	(0.0236)	(0.0256)	(0.0225)
Price Inc.	168.77	82.84	81.09	73.82	45.68	73.08
95% Int.	(-654,1151)	(-531,1109)	(37,229)	(36,223)	(35,247)	(32,173)
Time Trend I	2	3	2	2	2	3
Shocks K	n.A.	n.A.	1	1	1	2
Supply Lags	n.A.	n.A.	0	1	2	0

Explaining World Production Area

World

	(1)	(2)	(3)	(4)	(5)	(6)
Shock ω_{t-1}	-0.0599***	-0.0620***				
	(0.0147)	(0.0186)				
$\mathbb{E}[p_t\|_{t-1}]$						
Observation	42	42				
Time Trend I	2	3				
Shock Lags K	n.a.	n.a.				

Explaining World Production Area

World

	(1)	(2)	(3)	(4)	(5)	(6)
Shock ω_{t-1}	-0.0599***	-0.0620***				
	(0.0147)	(0.0186)				
$\mathbb{E}[p_t\|_{t-1}]$			0.0603***	0.0446***	0.0645***	0.0568***
			(0.0131)	(0.0128)	(0.0123)	(0.0126)
Observation	42	42	42	42	41	41
Time Trend I	2	3	2	3	2	3
Shock Lags K	n.a.	n.a.	1	1	2	2

Explaining World Production Area

United States

	(1)	(2)	(3)	(4)	(5)	(6)
Shock ω_{t-1}	-0.2642***	-0.2512***				
	(0.0654)	(0.0826)				
$\mathbb{E}[p_t\|_{t-1}]$			0.2767***	0.1906***	0.2936***	0.2302***
			(0.0516)	(0.0514)	(0.0482)	(0.0498)
Observation	42	42	42	42	41	41
Time Trend I	2	3	2	3	2	3
Shock Lags K	n.a.	n.a.	1	1	2	2

Explaining World Production Area

Brazil

	(1)	(2)	(3)	(4)	(5)	(6)
Shock ω_{t-1}	-0.3111***	-0.2304**				
	(0.0731)	(0.0897)				
$\mathbb{E}[p_t \vert_{t-1}]$			0.3832***	0.2509***	0.3694***	0.2367***
			(0.1040)	(0.0836)	(0.0972)	(0.0833)
Observation	42	42	42	42	41	41
Time Trend I	2	3	2	3	2	3
Shock Lags K	n.a.	n.a.	1	1	2	2

Explaining World Production Area

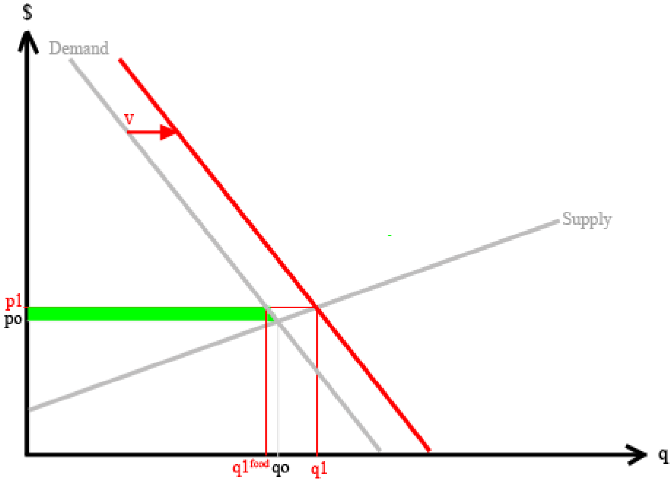
China

	(1)	(2)	(3)	(4)	(5)	(6)
Shock ω_{t-1}	-0.0256	-0.0424				
	(0.0272)	(0.0340)				
$\mathbb{E}[p_t\|_{t-1}]$			0.0313	0.0459*	0.0331	0.0672**
			(0.0278)	(0.0270)	(0.0259)	(0.0259)
Observation	42	42	42	42	41	41
Time Trend I	2	3	2	3	2	3
Shock Lags K	n.a.	n.a.	1	1	2	2

Implications

- Ethanol mandate: 5% of world caloric production
  - Food prices increase 33 percent
- Loss in consumer surplus: 170 billion annually
  - But: offsetting increase in producer surplus
  - Potential consumer surplus from lower fuel prices
  - Elastic supply

Implications



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- Loss in consumer surplus: 170 billion annually
  - But: offsetting increase in producer surplus
  - Potential consumer surplus from lower fuel prices
    - Rajagopal (2007)
    - Need demand / supply elasticity of fuels
  - Elastic supply
    - Lower price increase
    - Larger expansion in area / yield
    - 2percent increase or 30 million acres
    - Land use constitutes 20% of CO_2 emissions

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    - Land use constitutes 20% of CO_2 emissions

Outline

Conclusions

- Demand and supply model of commodity calories
- What's new?
  - Aggregation of crops by caloric content
  - New supply instrument (instrumented lagged price)
- Major results
  - Significant supply and demand elasticities
  - Previous literature found insignificant supply elasticities
- Implications for U.S. ethanol mandate
  - Predicted to raise world prices by 33 percent
  - Loss of consumer surplus 170 billion annually
  - Expansion in area by 2 percent (30 million acres)

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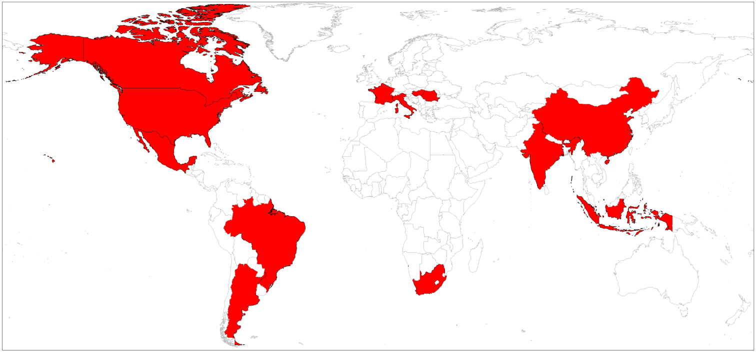
Outline

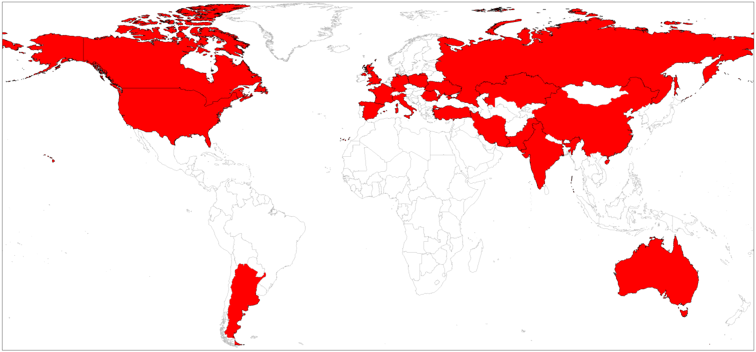
Major Agricultural Producers

Maize: Production Share greater than 1 Percent



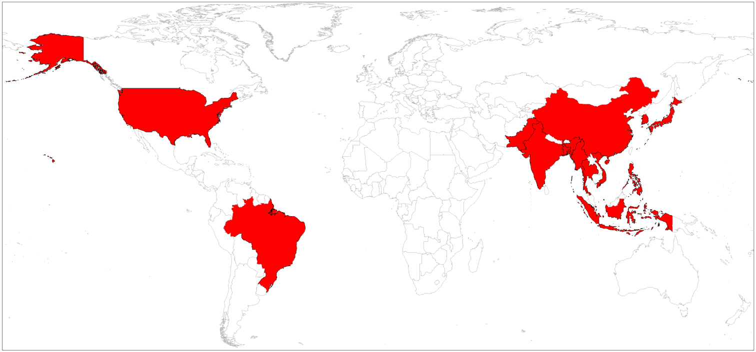
Major Agricultural Producers

Wheat: Production Share greater than 1 Percent



Major Agricultural Producers

Rice: Production Share greater than 1 Percent



Major Agricultural Producers

Soybeans: Production Share greater than 1 Percent

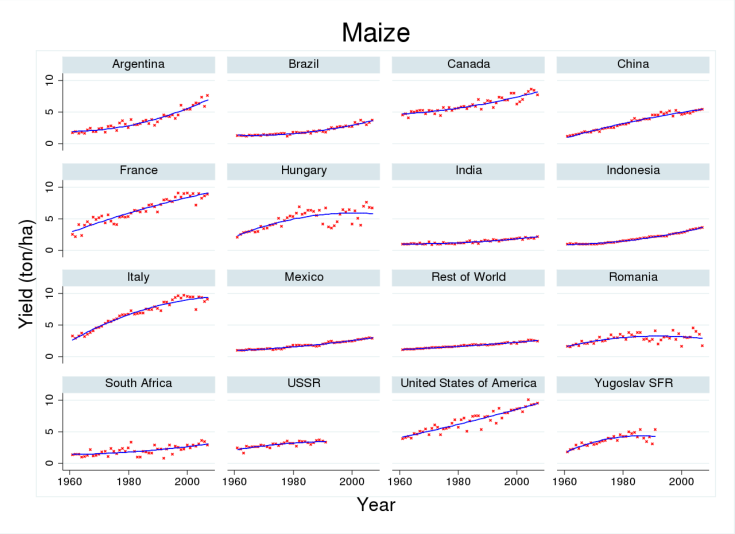
Production Shares

Country	Share	Country	Share
Wheat		**Maize**	
USSR	21.23	United States of America	42.00
China	14.05	China	15.66
United States of America	12.07	Brazil	5.21
India	8.53	USSR	3.52
Russian Federation	6.86	Mexico	3.01
France	5.33	Yugoslav SFR	2.47
Canada	4.81	Argentina	2.35
Turkey	3.48	France	2.32
Australia	3.13	Romania	2.15
Germany	2.89	South Africa	2.01
Ukraine	2.69	India	1.91
Pakistan	2.49	Italy	1.54
Argentina	2.23	Hungary	1.41
Italy	2.06	Indonesia	1.26
United Kingdom	2.01	Canada	1.15
Kazakhstan	1.87	Rest of World	14.07
Iran, Islamic Republic of	1.54		
Poland	1.38		
Yugoslav SFR	1.29		
Romania	1.27		
Spain	1.16		
Czechoslovakia	1.05		
Rest of World	12.12		

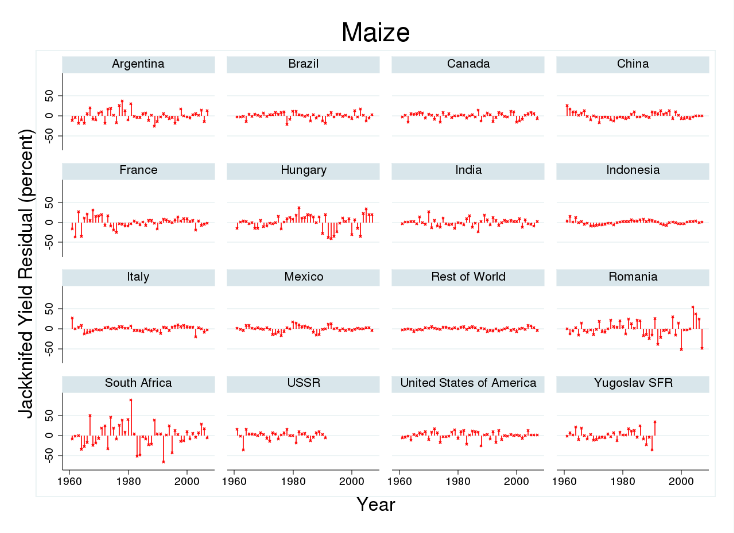
Production Shares

Country	Share	Country	Share
Rice		**Soybeans**	
China	34.44	United States of America	56.73
India	20.64	Brazil	14.43
Indonesia	7.50	China	13.05
Bangladesh	5.48	Argentina	6.62
Thailand	4.27	India	1.63
Vietnam	3.97	Canada	1.04
Japan	3.67	Rest of World	6.49
Myanmar	3.12		
Brazil	2.08		
Philippines	1.87		
Korea, Republic of	1.59		
United States of America	1.44		
Pakistan	1.07		
Rest of World	8.86		

Jackknifed Residuals



Jackknifed Residuals



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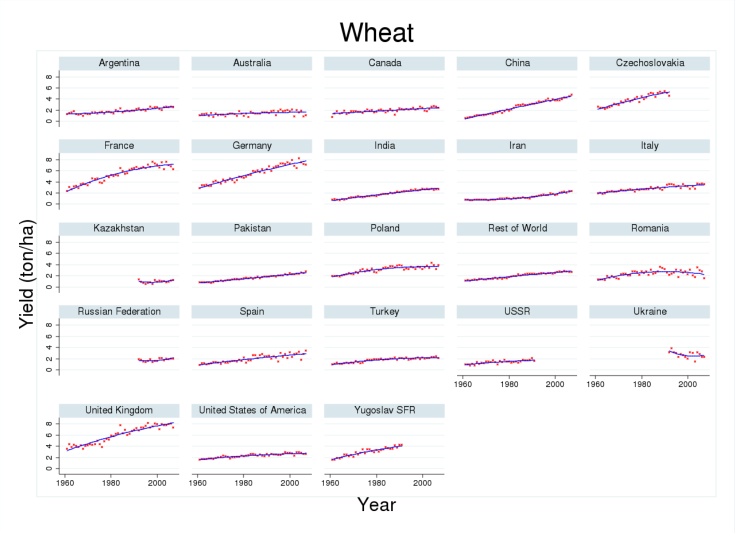
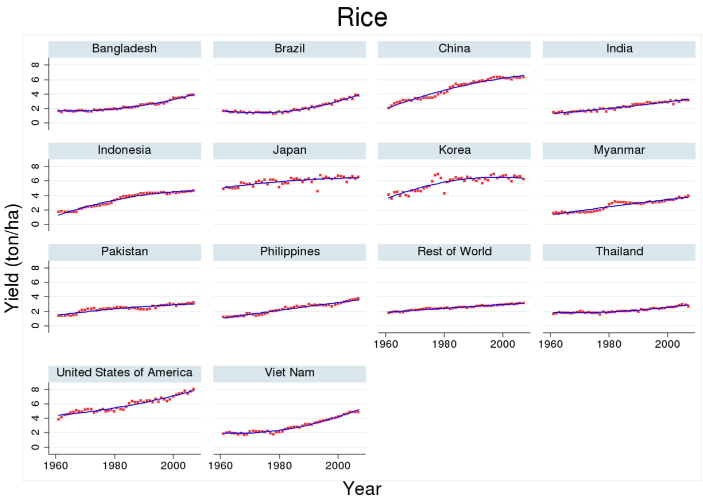


Jackknifed Residuals

Jackknifed Residuals



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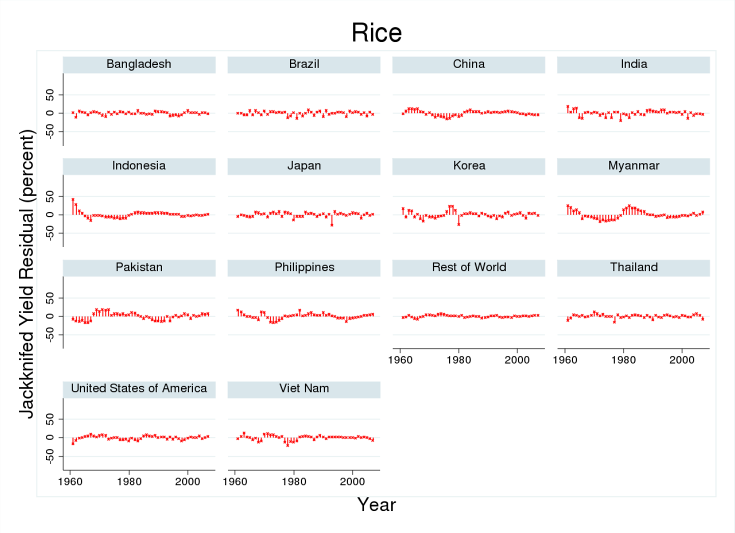

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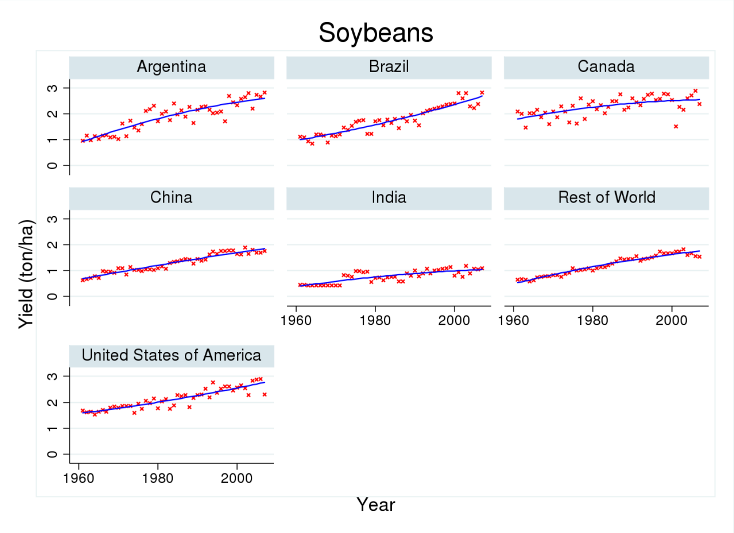

Jackknifed Residuals