U.S. Agricultural Productivity: Measurement and Structural Changes

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***The views expressed herein are those of the authors, and not necessarily those of the U.S. Department of Agriculture**

Introduction

- Growth in agricultural productivity has long been chronicled as the single most important source of economic growth in the U.S. farm sector
- The major sectoral productivity studies share this conclusion. (Kendrick and Grossman, 1980; Jorgenson, Gollop, and Fraumeni, 1987; Jorgenson and Gollop, 1992)
- Jorgenson, Ho, and Stiroh (2005) find that productivity growth in agriculture averaged 1.9 percent per year over the 1977-2000 period and accounted for almost 80 percent of the growth of output
- Moreover, only three of the forty-four sectors covered by the Jorgenson et al. study exhibited higher rates of productivity growth than did agriculture
- Yet, the recent surge in commodity prices raise concerns about a productivity slowdown

Overview of Presentation

- In the following, we provide a review of the methods/data underlying USDA's productivity estimates
- Identify the sources of growth in agriculture
- And provide a rigorous assessment of the slowdown hypothesis

The USDA's Productivity Accounts

- The USDA has been monitoring agriculture's productivity performance for decades
- In fact, in 1960, the USDA was the first agency to introduce multifactor productivity measurement into the Federal statistical program
- Today the USDA's Economic Research Service (ERS) routinely publishes productivity measures based on a sophisticated system of production accounts (Ball et al., 1999; Ball, Wang and Nehring, 2012)

Measurement--Methodology

- The official statistics are based on the translog transformation frontier
- The translog model relates the growth rates of multiple outputs to the cost-share weighted rates of growth of labor, capital, and intermediate inputs
- Total Factor (Multifactor) Productivity
  - The change in productivity growth is the difference between output growth and input growth.

$$\ln\left[\frac{TFP_t}{TFP_{t-1}}\right] = \sum\left[\frac{R_{it} + R_{i,t-1}}{2}\right]\ln\left[\frac{Y_{it}}{Y_{it-1}}\right] - \sum\left[\frac{W_{jt} + W_{j\,t-1}}{2}\right]\ln\left[\frac{X_{jt}}{X_{jt-1}}\right]$$

Measurement--Output

- The accounts are consistent with a gross output model of production
- Output is defined as gross production leaving the farm, as opposed to real value added
- Translog indexes of output are formed by aggregating over agricultural goods and services using revenue-share weights based on shadow prices

Measurement--Intermediate Input (I)

- The USDA measure of output is equated with gross production. Therefore, inputs of intermediate goods, obviously crucial to agricultural production, are treated symmetrically with labor and capital inputs

- Price and quantity data corresponding to purchases of feed, seed, and livestock are available and enter the calculation of intermediate input

- Translog indexes of energy inputs are calculated by weighting the growth rates of petroleum fuels, natural gas, and electricity by their shares in overall value of energy inputs

Measurement--Intermediate Input (II)

- Pesticides and fertilizer are important intermediate inputs, but price/consumption data require adjustment since inputs have undergone significant changes in input quality
- We construct price indexes for pesticides and fertilizer using hedonic methods
- The corresponding quantity indexes are formed implicitly by taking the ratio of the value of each aggregate to corresponding hedonic price index

Measurement--Intermediate Input (III)

- Finally, price and implicit quantity indexes are calculated for purchased services (e.g., custom machine services; contract feeding of livestock; contract labor services)

- A translog index of total intermediate input is calculated by weighting the growth rates of each category of intermediate input by their value shares in the overall value of intermediate inputs

Measurement– Labor (I)

- The labor accounts incorporate demographic cross-classifications of the agricultural labor force developed by Jorgenson, Gollop, and Fraumeni
- Hours worked and compensation per hour are cross-classified by sex, age, education, and employment class (employee versus self-employed and unpaid family workers)
- Compensation of self-employed and unpaid family workers is imputed based on mean wage of hired workers with the same demographic characteristics

Measurement—Labor (II)

- Indexes of labor input are constructed using demographically cross-classified hours and compensation data
- Labor hours having higher marginal productivity (wages) are given higher weights in the index than hours having lower marginal productivities
- This procedure explicitly adjusts the time series of labor input for “quality” changes in labor hours

Measurement– Capital (I)

- Measurement of capital input begins with estimating capital stock and rental price for each asset type. Stocks of depreciable capital are the cumulation of all past investments adjusted for discards of worn-out assets and loss of efficiency of assets over their service life

- Asset discards are calculated based on an assumed mean service life for a homogeneous group of assets and a distribution of actual discards around this mean service life.

- We assume that the discard distribution is the normal distribution truncated at points two standard deviations above and below the mean

Measurement– Capital (II)

- Efficiency loss (d) is assumed to be a function of age (L)of the asset. ß is a curvature or decay parameter. The function relating efficiency to age of the asset is approximated by a rectangular hyperbola concave to the origin.

$$d_\tau = (L-\tau)/(L-\beta\tau), 0 \leq \tau \leq L \qquad d_\tau = 0, \tau \geq L$$

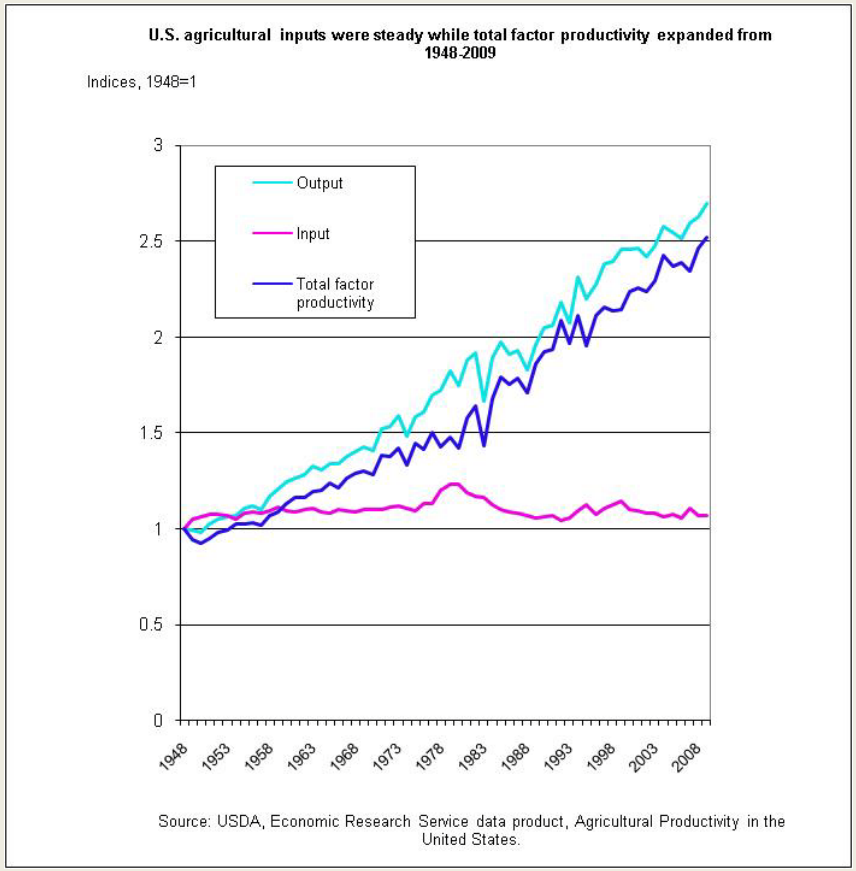
- Capital rental prices are derived based on the correspondence between the purchase price of the asset and the discounted value of service flows from that asset

- The same pattern of decline in efficiency is used for both capital stock and the rental price of capital, so that the requirement for internal consistency of the measure of capital input is met

Measurement--Land

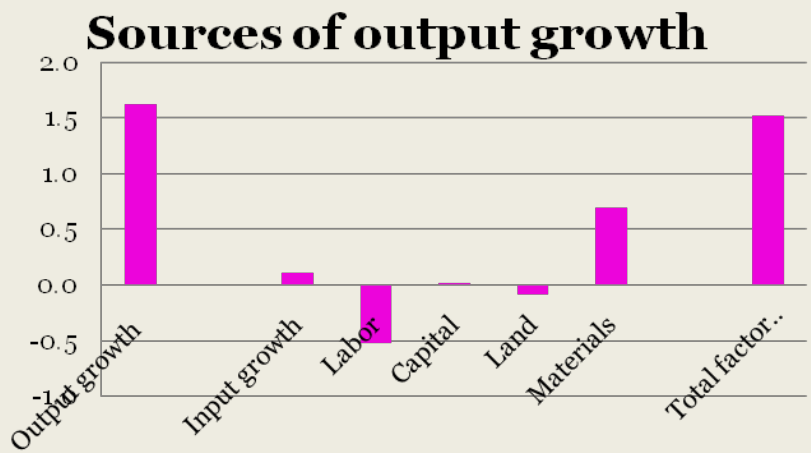
- The stock of land is measured as an implicit quantity
- We assume that land in each county is homogeneous, hence aggregation is at the county level
- Indexes of capital input are formed by aggregating over the various capital assets using cost-share weights based on asset-specific rental prices
- The resulting measure of capital input is adjusted for changes in asset quality

Trends in U.S. agricultural output, input, and TFP growth



- The level of U.S. farm output in 2009 was 170 percent above the 1948 level--grew at an average annual growth rate of 1.63 %.
- Average input use increased only 0.11 % annually.
- Output growth was due almost solely to productivity growth.
- TFP grew at an annual growth rate of 1.52% over 1948-2009.

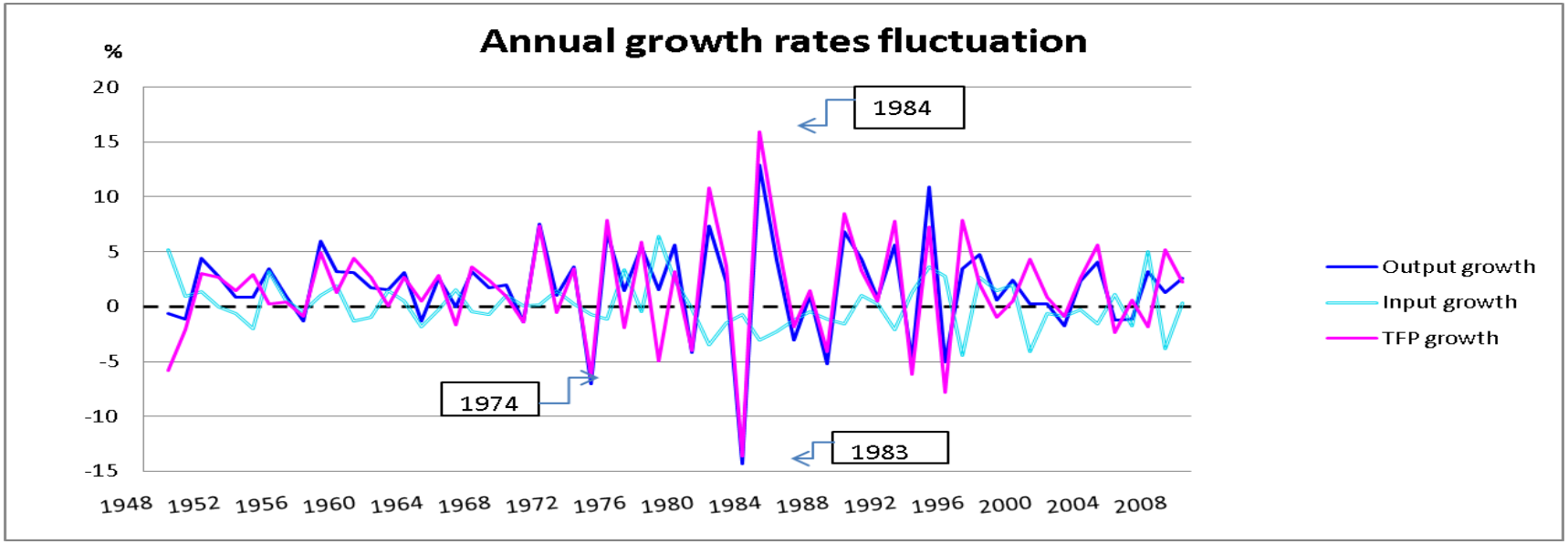
Sources of output growth (1948-2009)



Sources of Growth	1948-2009
Output growth	1.63
Input growth	0.11
Labor	-0.52
Capital	0.02
Land	-0.08
Materials	0.69
Total factor productivity	1.52

- Output grew at 1.63 % per annum
- Input grew at 0.11% per annum
- labor input declined at a 2.6% average annual rate. When weighted by its 20% cost share, the contraction in labor contributes an average of -0.52 percentage points to output growth.
- Capital contributed an average of 0.02 percentage points to output growth annually
- Land decreased over time and contributed to -0.08 percentage points to output growth annually.
- Increasing materials account for most of input growth and contributed an average of 0.69 percentage points to output growth
- TFP growth contributed 1.52 percentage points per annum to output growth

Volatility in agricultural output and TFP growth



- TFP growth moves attendantly with output growth
- Output growth oscillation has been greater since the 1980s, so has TFP growth
- Input growth volatility is smaller compared to the others

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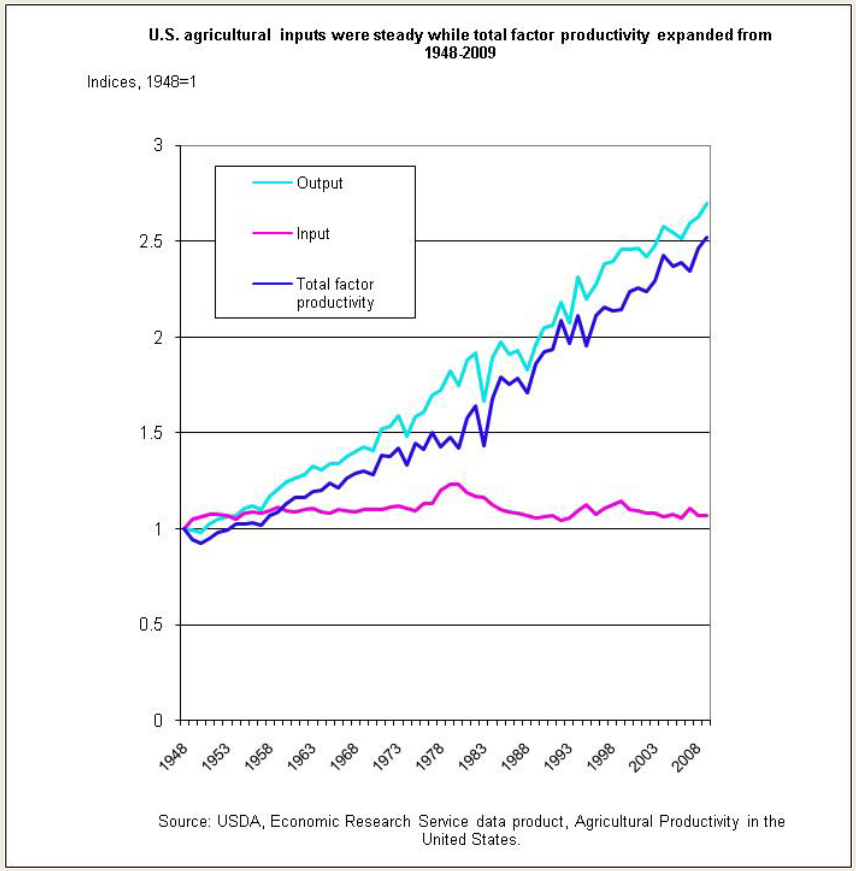

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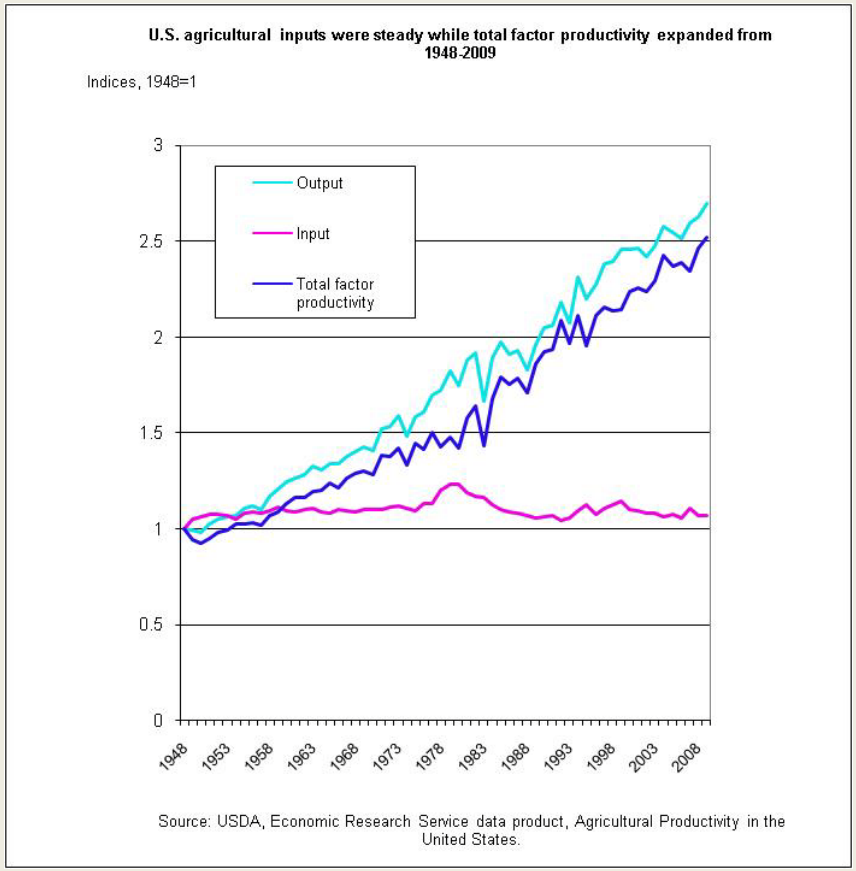

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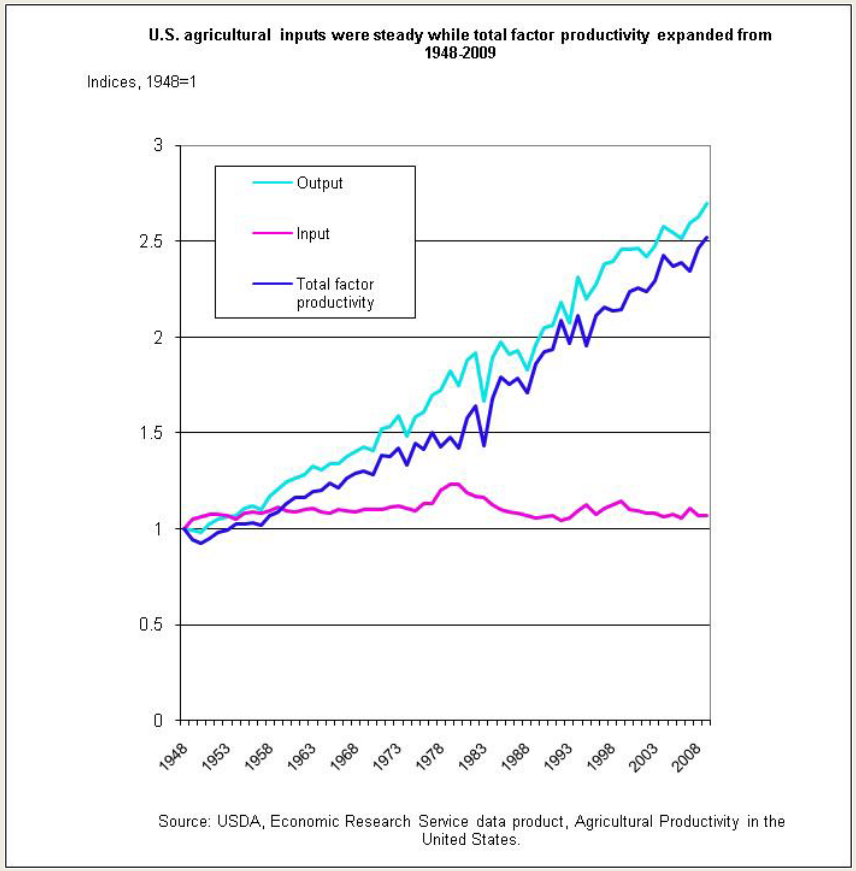

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Is U.S. agricultural productivity slowing?

Observations:

- Major crop prices increased in recent years, due to energy shock or a productivity slowdown?

  --food crop price index doubled from 2002 to 2008 but dropped in 2009.
- Crop yield growth slowed in 1990-2000

  --but rebounded in 2000-2009
- Public research funding has been flat in many years

  --but research investment has a long return period
- James et al. (2009) assert that U.S. agricultural productivity has been through substantial structural change and productivity growth has slowed down since 1990 based on data up to 2002.

  --Wang (2010) found no significant evidence of a U.S. agricultural productivity slowdown in recent years using ERS data up to 2008.

U.S. agricultural productivity slowdown: what are the facts?

- Were the lower average productivity growth rates in recent decades due to a long-run productivity slowdown caused by slowing public research funding or short term fluctuations caused by unfavorable weather?
- If there was a productivity slowdown or structure change, when and why?
- This is an important issue: If productivity growth falters, growing global demand will likely lead to sharply higher food prices and to increased environmental stress.

Test for the slowdown hypothesis

- Previous studies either test for an arbitrary candidate breakdate or pick a breakdate based on some known feature of the data. But, the tests results can be 'uniformative' because the true breakdate can be missed or 'misleading' because the breakdate is endogenous and the test is likely to indicate a break when none in fact exists.

- To address the slowdown hypothesis, we posit a simple trend model, and test the null hypothesis of a stable linear model against the alternative of 'breaks' in the parameters in the time series regression.

$$\ln TFP = c_0 + \tau_0 t + e_t,$$

$$\ln TFP = c_0 + c_1 D_{B_1} + \tau_0 t + e_t$$

$$\ln TFP = c_0 + c_1 D_{B_1} + \tau_0 t + \tau_1 D_{B_2} t$$

τ: TFP growth rate;

where D_{B1}=1 if t>T_{B1}, and zero otherwise, D_{B2}=1 if t>T_{B2} and zero otherwise, and T_{Bi}, i=1,2, represent breakdates.

Test for structural changes

- A structural change in trend indicates a change in the rate of productivity growth; a structural change in intercept indicates a TFP mean shift
- We conduct Elliott and Müller (2006) qLL test to assess the general persistence of the time variation in the regression coefficients in (1)
  - Results show there are structural breaks in intercept and trend
- We conduct unit root test with and without structural changes
  - Results show the TFP series is trend stationary
- We select the intercept break—1985—based on Zivot-Andrews (1992) test, and use a residual variance method to select the appropriated trend break—1974
- The Zivot and Andrews unit root test is based on the alternative hypothesis that the time series is trend stationary with a one-time break in the level or trend or both occurring at an unknown point in time.

Results (I)—Elliott-Muller qLL tests

Table 2 Elliott-Muller qLL test results

Breaks	qLL statistics[1]	
without break	-17.41	**
with intercept break at 1985 only	-16.32	**
with trend break at 1985 only	-22.11	***
with intercept and trend break at 1985	-13.44	*
with intercept break at 1985 and trend break at 1974	-9.05	

Note 1: The null hypothesis is coefficients are fixed over the sample period
Note 2: '*' indicates significant at 5% level; '**' indicates significant at 10% level, '***' indicates significant at 1% level.

Results (II)—Unit root tests

Table 3 Results of unit root tests

Tests	Test result
Unit root test without break	
ADF unit root test	
without trend	nonstationary
with trend	stationary
KPSS unit root test	
without trend	nonstationary
with trend	stationary
PP unit root test	
without trend	nonstationary
with trend	stationary
Unit root test with break	
CMR unit root test	
AO1--with one mean shift	nonstationary
AO2--with double mean shifts	nonstationary
IO1--with one mean shift	nonstationary
IO2--with double mean shifts	nonstationary
Z-Andrews unit root test with trend	
both trend and mean shift with break at 1985	stationary

Note1: the significance level for the test is 5%.

Results (III)—Alternative model estimates

Table 4. Results of OLS regression model estimation

Models	Model A[1] coefficients	t statistics		Model B[2] coefficients	t statistics		Model C[3] coefficients	t statistics	
Intercept	3.6528	270.00	***	3.6461	325.62	***	3.6317	307.50	***
t	0.0153	25.63	***	0.0156	30.88	***	0.0171	22.30	***
d1985				0.0920	2.02	**	0.0718	4.68	***
tD1985	0.0013	3.11	***	-0.0007	-0.68				
tD1974							-0.0015	-2.56	**
D-W statistics	2.1135			2.2666			1.9846		
Pr < DW	0.5732			0.7437			0.3224		
Pr>DW	0.4268			0.2563			0.6776		
R^2	0.9877			0.9897			0.9965		
adjusted R^2	0.9873			0.9892			0.9917		

Note 1: Model with trend break at 1985 only

Note 2: Model with mean shift and trend break at 1985

Note 3: Model with mean shift at 1985 and trend break at 1974

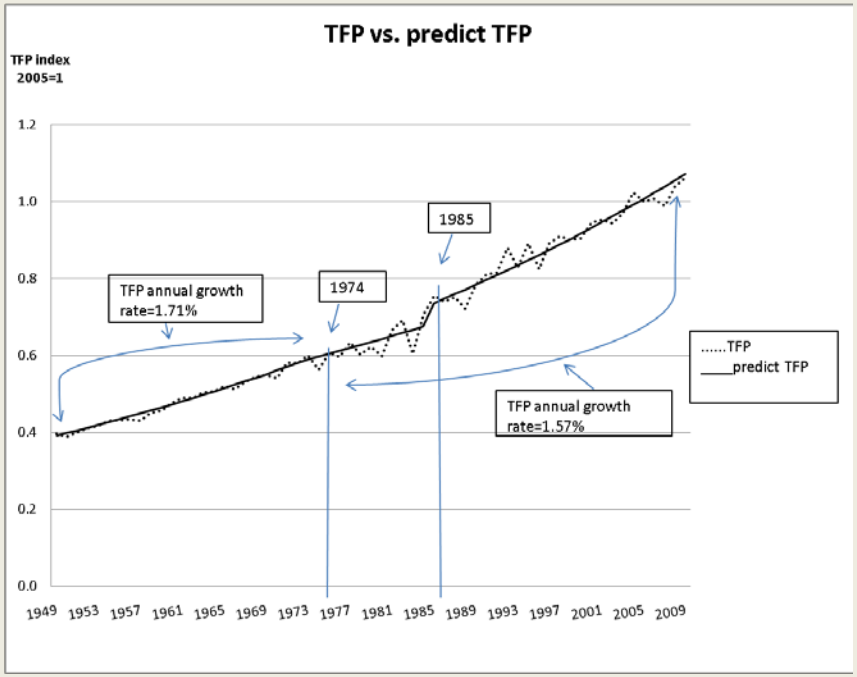
Note 4: '***' indicates significant at 1% level; '**' indicates significant at 5% level; "*' indicates significant at 10% level.

Results (IV)—Structural breaks and productivity slowdown

Table 5: Test Results of Productivity Slowdown

	Annual productivity growth rate (%)		Difference	
Models with alternative breaks	First period (A)	Second period (B)	(B-A)	
A. With trend break at 1985 only	1.54	1.67	0.12	***
B. With both intercept and trend breaks at 1985	1.57	1.50	-0.07	
C. With intercept break at 1985 and trend break at 1974	1.71	1.56	-0.15	**

U.S. agriculture productivity slowdown: when and why?



- A significant negative trend break in 1974 slowed the productivity growth rate by 0.15 percentage points from an average of 1.71% per annum to 1.56% per annum.

- The structural change in 1985 is a one-time shift that raises the average TFP to a higher level. Yet, the productivity growth rate remains the same as in the post-1974 era. There is no further productivity slowdown in the long run since 1974.

Conclusions

- There are concerns about a productivity slowdown. If productivity growth falters, growing global demand will likely lead to sharply higher food prices and to increased environmental stress.
- The break in 1974 was coincident with 1973 oil embargo that resulted in a rapid and unexpected rise in energy prices. The rise in energy prices accelerated the rate of obsolescence of the stock of capital in agriculture. The conventional measures of productivity growth may fail to identify this effect.
- A structural change that resulted in a one-time TFP level shift in 1985 may be attributed to multiple factors including a recovery from an economic recession in 1981-1983, a rebound from 1983's bad weather shock, and changes in farm policy since 1985.

Q & A

http://www.ers.usda.gov/data/agproductivity/

Thank you!