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Farm Size and Productivity Growth in the United States Corn Belt

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Stylized facts about farm size and farm productivity in the U.S.

- Production has shifted to larger farms
  - 1982-2007: weighted-median farm size almost doubled from 589 to 1105 acres
  - 1982-2007: weighted-median acres harvested more than doubled for major field crops
  - 1987-2007: share of output from farms with sales of at least $1 million increased from 30% to over 60%
- Farms have become more productive
  - 1982-2012: Aggregate TFP increased 46% (1.3% per year)
  - Corn yields increased 50% (1980-84 to 2010-14)

Main questions

- What has caused the shift in production to large farms?
  - Have economies of scale provided an incentive for the consolidation?
- Is consolidation of production likely to continue?
  - Are productivity advantages of large farms increasing or are small farms catching up?

Main questions (cont.)

- What is the relationship between structural change and aggregate productivity growth?
  - How much of past aggregate TFP growth can be explained by shift to larger farms?
    - Most research focuses on technological progress as source of TFP growth
    - But shift in production to larger more productive farms will also increase aggregate TFP
  - If consolidation slows, how much could this affect future productivity growth?
  - How could policies targeting small farms vs. large farms affect aggregate TFP growth?
    - More or less “bang-for-the buck” in targeting small farms?

Empirical approach

- 1982-2012 Census of Agriculture data on crop farms in Heartland region
- Compare TFP of across 5 farm size categories
- Compare TFP growth rates across farm size categories
- Estimate how much of aggregate TFP growth due to structural change versus farm-level TFP change
- Estimate effect of productivity-enhancing policies targeting small vs. large farms on aggregate TFP

How to compare the productivity *change* of similarly-sized farms over long periods?

- Approach 1: Panel data with fixed farm sizes
  - Assign farms to time-invariant size categories and estimate TFP of each farm in each year
  - Allows a straightforward comparison across sizes and time (if farms do not change size)
  - But … problems over long periods (e.g. 30 years):
    - Many farms do not remain in same size category
      - High 5-year transition rates
      - So not a comparison of the same size farms at 2 points in time
    - Sample attrition bias
      - High 5-year exit rates
      - Continuing farms not representative of population

How to compare the productivity *change* of similarly-sized farms over long periods?

- Approach 2: Size cohorts with cross-sectional or panel data
  - Assign farms to a size category in each period (farms can move between size categories)
  - Allows for comparison of the same size farms in different periods
  - Can avoid sample attrition bias if surveys are representative in each year
  - But … does not capture changes to aggregate productivity resulting from structural change

Limitation of cohort approach: an example

- 2 farm sizes (small and large) and increasing returns to scale:
  - TFP: small = 1, large = 2
- Consolidation of production
  - Period 1: 50% of production by small and large
  - Period 2: 25% small, 75% large
- Aggregate TFP increases 17% with no farm-level TFP change:
  - Aggregate TFP period 1 = 0.50*1 + 0.50*2 = 1.5
  - Aggregate TFP period 2 = 0.25*1 + 0.75*2 = 1.75

Components of aggregate TFP change

- If aggregate TFP is the sales-weighted average of each size category

$$TFP = \theta_1 * TFP_1 + \theta_2 * TFP_2 + \cdots \theta_s * TFP_s$$

- Then the change in aggregate TFP between periods depends on change in TFP for each farm size and change in farm size distribution:

$$\Delta TFP = (\Delta TFP_1 \cdot \bar{\theta}_1 + \Delta TFP_2 \cdot \bar{\theta}_2 + \cdots \Delta TFP_s \cdot \bar{\theta}_s) + (\Delta\theta_1 \cdot \overline{TFP_1} + \Delta\theta_2 \cdot \overline{TFP_2} + \cdots \Delta\theta_s \cdot \overline{TFP_s})$$

- $\Delta TFP_s \cdot \bar{\theta}_s$ is the contribution to aggregate productivity change from farms in size category *s* that is due to productivity change in that size category

Census of Agriculture data

- Farm-level data collected every 5 years by USDA-NASS
- 1982-2012 (longest span available for farm level data)
- Data challenges
  - Input costs only collected on "long form" before 2002
  - Questions on input costs for production contract operations changed in 2002 – so exclude livestock
- Focus on common but relatively homogenous farm type
  - Farms that specialize in major commodity crops
    - Corn (grain), wheat, soybeans, sorghum (grain), barley, oats
  - At least 90% of sales from these crops
  - At least 90% of harvested acres in these crops
  - Located in Heartland region

Farm Resource Regions

Basin and Range

- Largest share of nonfamily farms, smallest share of U.S. cropland.
- 4% of farms, 4% of value of production, 4% of cropland.
- Cattle, wheat, and sorghum farms.

Northern Great Plains

- Largest farms and smallest population.
- 5% of farms, 6% of production value, 17% of cropland.
- Wheat, cattle, sheep farms.

Heartland

- Most farms (22%), highest value of production (23%), and most cropland (27%).
- Cash grain and cattle farms.

Northern Crescent

- Most populous region.
- 15% of farms, 15% of value of production, 9% of cropland.
- Dairy, general crop, and cash grain farms.

Eastern Uplands

- Most small farms of any region.
- 15% of farms, 5% of production value, and 6% of cropland.
- Part-time cattle, tobacco, and poultry farms.

Fruitful Rim

- Largest share of large and very large family farms and nonfamily farms.
- 10% of farms, 22% of production value, 8% of cropland.
- Fruit, vegetable, nursery, and cotton farms.

Prairie Gateway

- Second in wheat, oat, barley, rice, and cotton production.
- 13% of farms, 12% of production value, 17% of cropland.
- Cattle, wheat, sorghum, cotton, and rice farms.

Mississippi Portal

- Higher proportions of both small and larger farms than elsewhere.
- 5% of farms, 4% of value, 5% of cropland.
- Cotton, rice, poultry, and hog farms.

Southern Seaboard

- Mix of small and larger farms.
- 11% of farms, 9% of production value, 6% of cropland.
- Part-time cattle, general field crop, and poultry farms.

Electronic files linking counties to the Farm Resource Regions are online at the ERS home page.

For more information about ERS publications and data, see our home page.

TFP Fisher index

- TFP index is a measure of outputs produced per unit of inputs, with prices used to weight the outputs and inputs.
- Outputs
  - Corn (grain), wheat, soybeans, sorghum (grain), barley, oats
  - Plus “other outputs” (residual sales, <10% of sales)
- Inputs
  - Land – harvested acres
  - Labor – cost of hired and contract labor plus estimated opportunity cost of own labor (subtract time working off-farm)
  - Machinery and equipment – implied annual cost based on reported value of machinery used on-farm (owned and rented)
  - Other variable inputs – reported expenses paid for fertilizer, chemicals, fuel, utilities and seeds

How to define farm size categories?

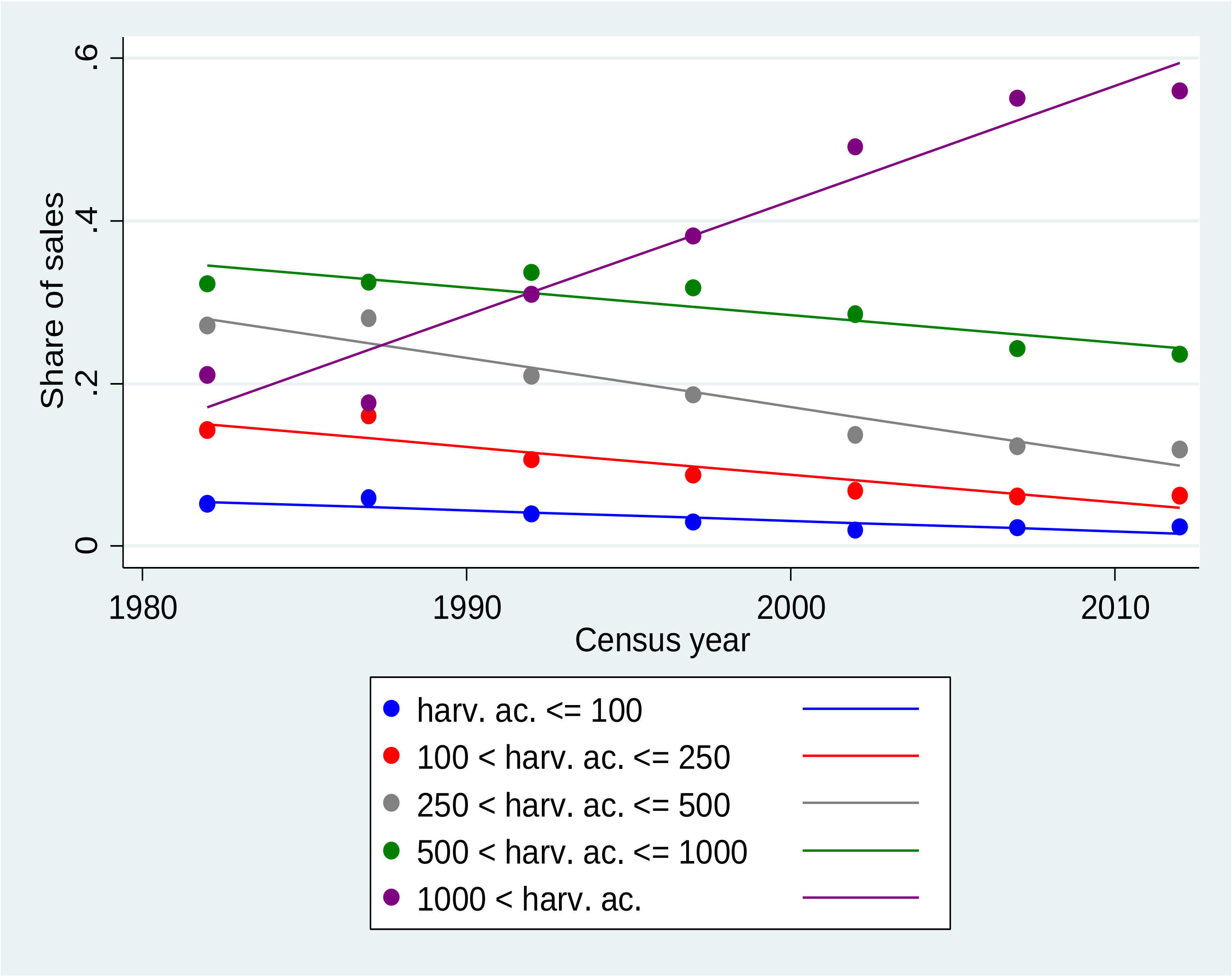
- Do not use output/sales because:
  - Can lead to spurious positive correlation between size and productivity
  - Output and sales vary a lot from year-to-year and across farms due to random weather, pests, etc.
  - Farms experiencing a good/bad year will have high/low sales and high/low productivity
- Use land quantity because:
  - Does not vary a lot from year-to-year due to random yield shocks
  - However, land is correlated with total inputs so measurement error could cause a spurious negative correlation between size and productivity
  - But, in U.S. land acreage (more so than land value) is accurately measured so measurement error is likely small.

Sample statistics by farm size category (harvested acres)

Outputs	0 – 100	100 – 250	250 – 500	500 – 1000	1000 +
Corn (grain) (bu.)	2336	9970	23366	48030	124251
Wheat (bu.)	133	365	705	1291	3734
Soybeans (bu.)	808	3115	6864	13542	32698
Sorghum (grain) (bu.)	2	10	31	67	243
Barley (bu.)	1	4	10	20	46
Oats (bu.)	20	61	92	93	108
Inputs					
Land (acres harv.)	45	167	365	711	1752
Labor ($)	7026	8944	11586	17140	39521
Machinery ($)	5301	11594	20655	37371	90392
Other inputs ($)	5815	20394	44362	92951	281082
Major crop sales ($)	14163	56737	129633	275174	814438
Corn yields (bu./harv.ac.)	114	124	129	133	134
Obs.	81247	60927	59260	68884	64945

What were sales shares for each size category and how did shares change?

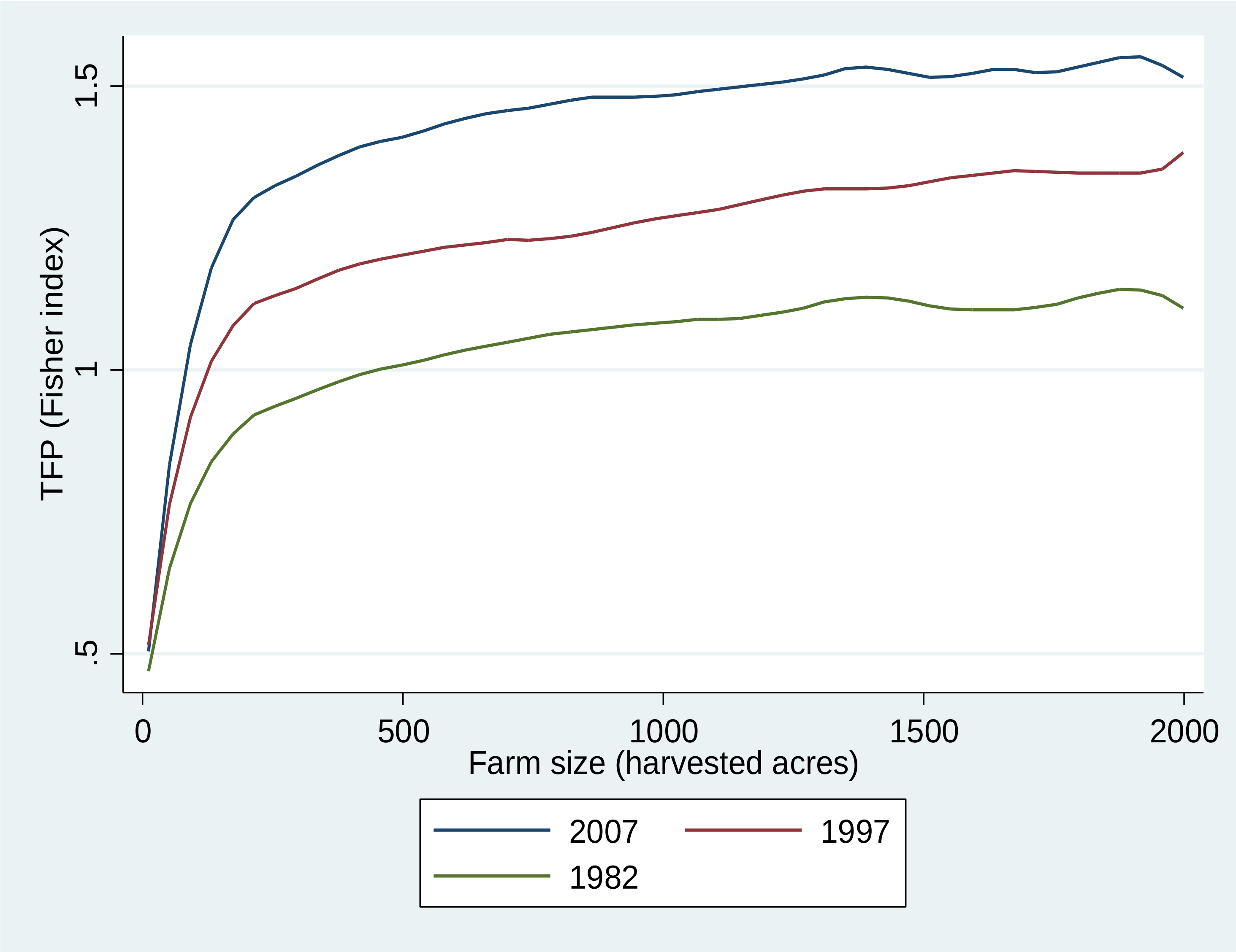
- Compute average sales for each size category and fit linear trend
- Substantial structural change over study period
  - Farms with 1000+ acres dramatically increased share of total sales:
    - 17% in 1982
    - 59% in 2012
  - All other size categories declined in sales share.
  - Mid-sized farms (250-500 acres) declined the most (in percentage points).



Share of sales
0
.2
.4
.6
1980
1990
2000
2010
Census year
harv. ac. <= 100
100 < harv. ac. <= 250
250 < harv. ac. <= 500
500 < harv. ac. <= 1000
1000 < harv. ac.

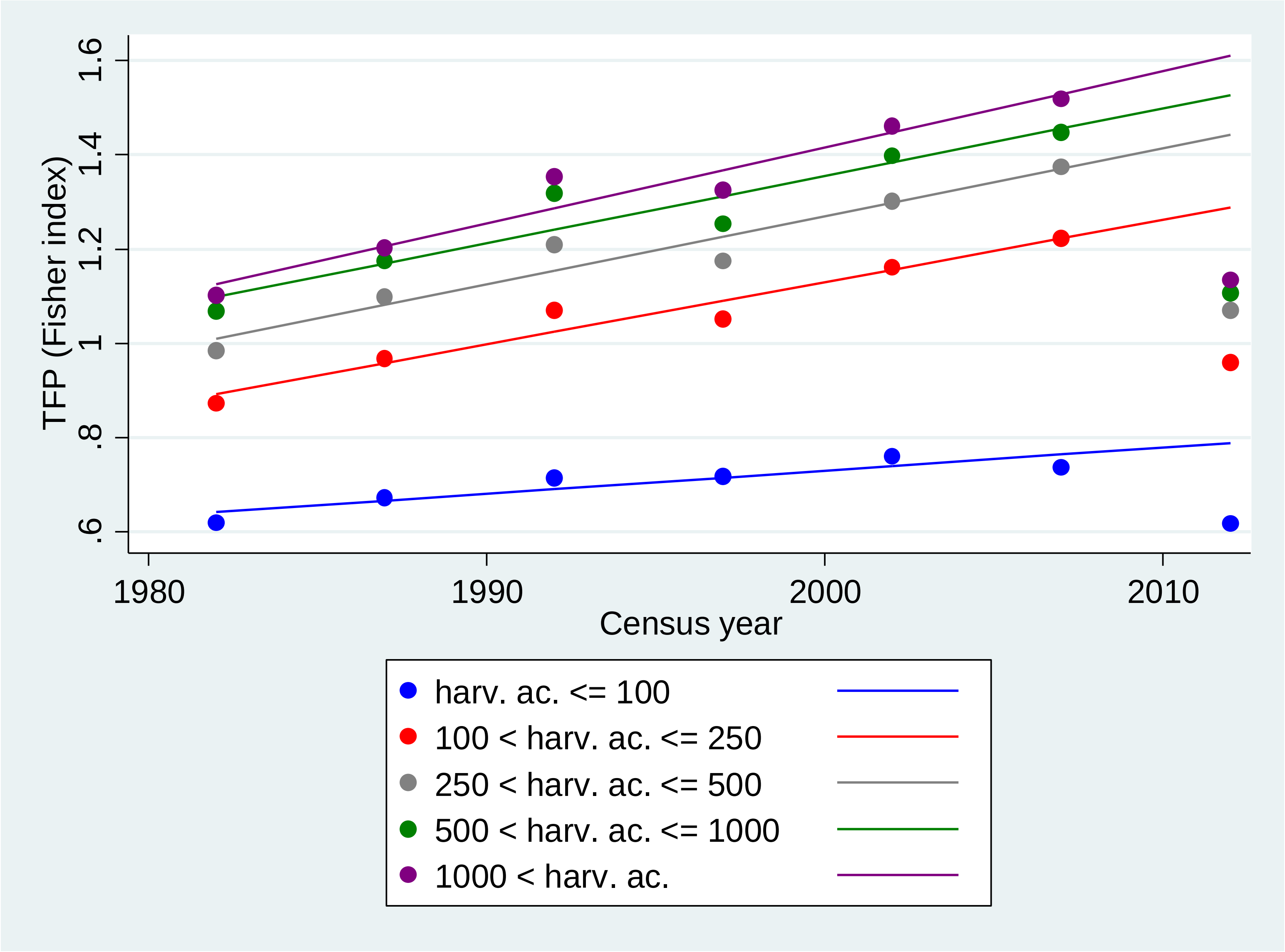
How does TFP vary across farm size and how did it change over time?

- Calculate Fisher TFP index for every farm in every year
- Kernel-weighted local polynomial regression of TFP on farm size shows:
  - TFP increasing with size in every year
  - TFP increasing over time for all sizes


TFP (Fisher index)
1.5
1
.5
0
500
1000
1500
2000
Farm size (harvested acres)
2007
1997
1982

How does TFP vary across farm size and how did it change over time?

- Calculate average Fisher TFP index by farm size category and year
- Estimate linear trend
  - Drop 2012 because of severe drought in Heartland region
  - Shows TFP increasing over time for all farm size categories
    - Slower increase for smallest size category



TFP (Fisher index)
1.6
1.4
1.2
1
.8
.6
1980
1990
2000
2010
Census year
harv. ac. <= 100
100 < harv. ac. <= 250
250 < harv. ac. <= 500
500 < harv. ac. <= 1000
1000 < harv. ac.

Components of aggregate TFP change

- Recall, the change in aggregate TFP between periods depends on change in TFP for each farm size and change in farm size distribution:

$$\Delta TFP = (\Delta TFP_1 \cdot \bar{\theta}_1 + \Delta TFP_2 \cdot \bar{\theta}_2 + \cdots \Delta TFP_s \cdot \bar{\theta}_s) +$$

$$(\Delta\theta_1 \cdot \overline{TFP}_1 + \Delta\theta_2 \cdot \overline{TFP}_2 + \cdots \Delta\theta_s \cdot \overline{TFP}_s)$$

- This can be written in terms of percent change:

$$\%\Delta TFP = 100 \frac{\Delta TFP}{TFP}$$

$$= \left(100 \frac{\Delta TFP_1}{TFP} \cdot \bar{\theta}_1 + 100 \frac{\Delta TFP_2}{TFP} \cdot \bar{\theta}_2 + \cdots 100 \frac{\Delta TFP_s}{TFP} \cdot \bar{\theta}_s\right) +$$

$$\left(\Delta\theta_1 \cdot 100 \frac{\overline{TFP}_1}{TFP} + \Delta\theta_2 \cdot 100 \frac{\overline{TFP}_2}{TFP} + \cdots \Delta\theta_s \cdot 100 \frac{\overline{TFP}_s}{TFP}\right)$$

Change in aggregate TFP (1982-2012): +54.8%

	% Change in TFP	Average Sales share	Contribution due to change in TFP	Change in Sales share	Average TFP as a % of Initial TFP	Contribution due to structural change
Size category (acres)	$100\frac{\Delta TFP_s}{TFP}$	$\bar{\theta}$	$100\frac{\Delta TFP_s}{TFP}\cdot\bar{\theta}_s$	$\Delta\theta$	$100\frac{\overline{TFP_s}}{TFP}$	$\Delta\theta_s\cdot 100\frac{\overline{TFP_s}}{TFP}$
0 – 100	**15.3**	**0.03**	**0.5**	**-0.04**	**75.0**	**-2.9**
100 – 250	**41.6**	**0.10**	**4.1**	**-0.10**	**114.4**	**-11.7**
250 – 500	**45.4**	**0.19**	**8.6**	**-0.18**	**128.6**	**-23.2**
500 – 1000	**45.0**	**0.29**	**13.3**	**-0.10**	**137.6**	**-14.0**
1000+	**50.8**	**0.38**	**19.4**	**0.42**	**143.4**	**60.7**
All farms			**45.9**			**8.9**

Aggregate TFP results

- Aggregate TFP grew 54.8% from 1982-2012
  - Implies 1.47% annual growth rate, a bit more than the average growth rate estimated by USDA for the entire sector (1.3%)
    - Farmland in Heartland is relatively flat and contiguous – more suitable to new machinery and precision agriculture technologies.
- 5/6 of aggregate TFP growth due to farm TFP change, 1/6 due to structural change
  - 45.9% = growth due to increasing TFP (i.e. TC, TEC) of representative farms in each category
  - 8.9% = growth due to change in farm size distribution
- Contribution due to TFP change (TC, TEC) increased steadily with farm size
  - 0.5 percentage points for smallest to 19.4 for largest
  - Contribution increases mainly because sales share increases with farm size
    - Smallest farms produced 3% of output compared to 38% for largest farms (on average)

Estimate effect of hypothetical targeted productivity-enhancing policies

- Possible policy examples:
  - Targeted subsidized credit or tax breaks to purchase new equipment
  - Targeted agricultural extension assistance

<u>Policy 1</u>: 10 pct. pt. increase in TFP growth for smallest farms

<u>Policy 2</u>: 10 pct. pt. increase in TFP growth for largest farms

- Retrospective analysis assumes no change in sales shares, only change in TFP growth rates

Target smallest farms: net change in aggregate TFP +0.2 pts.

	% Change in TFP	Average Sales share	Contribution due to change in TFP	Change in Sales share	Average TFP as a % of Initial TFP	Contribution due to change in Sales share
Size category (acres)	$100\frac{\Delta TFP_s}{TFP}$	$\bar{\theta}$	$100\frac{\Delta TFP_s}{TFP}\cdot\bar{\theta}_s$	$\Delta\theta$	$100\frac{\overline{TFP_s}}{TFP}$	$\Delta\theta_s\cdot 100\frac{\overline{TFP_s}}{TFP}$
0 – 100	**~~15.3~~ 25.3**	**0.03**	**~~0.5~~ 0.9**	**-0.04**	**~~75.0~~ 78.5**	**~~-2.9~~ -3.1**
100 – 250	**41.6**	**0.10**	**4.1**	**-0.10**	**114.4**	**-11.7**
250 – 500	**45.4**	**0.19**	**8.6**	**-0.18**	**128.6**	**-23.2**
500 – 1000	**45.0**	**0.29**	**13.3**	**-0.10**	**137.6**	**-14.0**
1000+	**50.8**	**0.38**	**19.4**	**0.42**	**143.4**	**60.7**
All farms			**~~45.9~~ 46.3**			**~~8.9~~ 8.7**

Target largest farms: net change in aggregate TFP +6.2 pts.

	% Change in TFP	Average Sales share	Contribution due to change in TFP	Change in Sales share	Average TFP as a % of Initial TFP	Contribution due to change in Sales share
Size category (acres)	$100\frac{\Delta TFP_s}{TFP}$	$\bar{\theta}$	$100\frac{\Delta TFP_s}{TFP}\cdot\bar{\theta}_s$	$\Delta\theta$	$100\frac{\overline{TFP_s}}{TFP}$	$\Delta\theta_s \cdot 100\frac{\overline{TFP_s}}{TFP}$
0 – 100	**15.3**	**0.03**	**0.5**	**-0.04**	**75.0**	**-2.9**
100 – 250	**41.6**	**0.10**	**4.1**	**-0.10**	**114.4**	**-11.7**
250 – 500	**45.4**	**0.19**	**8.6**	**-0.18**	**128.6**	**-23.2**
500 – 1000	**45.0**	**0.29**	**13.3**	**-0.10**	**137.6**	**-14.0**
1000+	**~~50.8~~ 60.8**	**0.38**	**~~19.4~~ 23.3**	**0.42**	**~~143.4~~ 149.1**	**~~60.7~~ 62.8**
All farms			**~~45.9~~ 49.7**			**~~8.9~~ 11.3**

Summary and conclusions

- Crop production in the Heartland has shifted to large farms
  - Market share of largest farms (>1000 acres) increased from 17% To 59%
  - Market share of smaller farms decreased
  - Midsized farms (250-500 acres) had the largest decline in market share: from about 30% to 10%
- Economies of scale have provided an incentive for this consolidation of production between 1982 and 2012
  - TFP increases with scale of production in every year
  - In 2012, midsized farms (250-500 acres) had unit costs that are 6% higher than the largest farms (>1000 acres), while the smallest farms (<100 acres) had unit costs that are 76% greater.

Summary and conclusions (cont.)

- Small farms are not “catching up” to larger farms in terms of productivity
  - There was no substantial difference in productivity growth rates among farms with more than 100 acres.
  - Smallest farms (0-100 acres) had a slower productivity growth rate
    - Productivity disadvantage of smallest farms increased
- Why have smallest farms lagged?
  - Some new technologies may have benefited large farms more than smallest farms
  - Smaller farms had lower adoption rates of new technologies – e.g. precision agriculture technologies

Summary and conclusions (cont.)

- A small but important share of past aggregate TFP growth can be explained by shift to larger farms.
  - Aggregate TFP increased 54.8%
  - About 1/6 of this growth was attributable to structural change
  - Now that most production is now on farms with more than 1000 acres, will consolidation slow? If so, then future productivity growth will likely also slow somewhat as a result.
- Past agricultural productivity growth was driven by large farms.
  - TFP change for largest farms contributed to 19.4 pts. to aggregate TFP growth compared to only 0.5 pts. for smallest farms – 39 times as much.
  - Difference mainly because large farms contribute more to total sales

Summary and conclusions (cont.)

- Because larger farms contribute more to total output, productivity increases on larger farms will have a greater impact on aggregate productivity growth.
  - Increasing productivity of 0-100 acre farms increased aggregate TFP by only 0.2 pts.
  - Increasing productivity of 1000+ acre farms increased aggregate TFP by 6.2 pts. – 31 times as much.
- Targeting small (large) farms would likely slow (speed up) consolidation, and this would further reduce (increase) aggregate productivity growth

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Extra slides follow

How do unit input costs vary by farm size?

- Do large farms have scale advantages in some inputs and not others? Why?

	Farm size (harvested acres)					
	0-100 (1)	100-250 (2)	250-500 (3)	500-1000 (4)	1000+ (5)	Difference between (1) and (5)
Labor						
1982	0.59	0.23	0.14	0.10	0.10	0.50
2012	0.68	0.19	0.11	0.08	0.06	0.62
2012-1982	0.09	-0.04	-0.03	-0.02	-0.04	0.13
Machinery						
1982	0.51	0.30	0.24	0.20	0.15	0.35
2012	0.55	0.31	0.25	0.23	0.19	0.36
2012-1982	0.04	0.01	0.01	0.03	0.04	0.00
Land						
1982	0.64	0.59	0.56	0.54	0.53	0.11
2012	0.79	0.72	0.69	0.68	0.69	0.10
2012-1982	0.15	0.13	0.13	0.14	0.16	-0.01
Variable inputs						
1982	0.47	0.44	0.43	0.42	0.43	0.04
2012	0.80	0.69	0.65	0.64	0.65	0.15
2012-1982	0.33	0.25	0.22	0.22	0.22	0.11
Total unit costs						
1982	2.21	1.56	1.37	1.25	1.21	1.01
2012	2.82	1.92	1.70	1.63	1.60	1.23
2012-1982	0.61	0.36	0.33	0.38	0.39	0.22

How do unit input costs vary by farm size?

- About 80% of cost difference between smallest and largest farms due to labor and machinery inputs
  - 50% due to labor
  - 30% due to machinery
- Why economies of scale in labor and machinery?
  - Family labor + available labor-saving technologies
  - Large farms better suited to large machinery
    - Larger contiguous fields
  - Transactions costs in machinery rental markets

How did unit input costs change over time?

- Did technological change cause the unit cost difference between small and large farms to expand?
- If so, which inputs provided a growing cost advantage for large farms? Why?

	Farm size (harvested acres)					
	0-100 (1)	100-250 (2)	250-500 (3)	500-1000 (4)	1000+ (5)	Difference between (1) and (5)
Labor						
1982	0.59	0.23	0.14	0.10	0.10	0.50
2012	0.68	0.19	0.11	0.08	0.06	0.62
2012-1982	0.09	-0.04	-0.03	-0.02	-0.04	0.13
Machinery						
1982	0.51	0.30	0.24	0.20	0.15	0.35
2012	0.55	0.31	0.25	0.23	0.19	0.36
2012-1982	0.04	0.01	0.01	0.03	0.04	0.00
Land						
1982	0.64	0.59	0.56	0.54	0.53	0.11
2012	0.79	0.72	0.69	0.68	0.69	0.10
2012-1982	0.15	0.13	0.13	0.14	0.16	-0.01
Variable inputs						
1982	0.47	0.44	0.43	0.42	0.43	0.04
2012	0.80	0.69	0.65	0.64	0.65	0.15
2012-1982	0.33	0.25	0.22	0.22	0.22	0.11
Total unit costs						
1982	2.21	1.56	1.37	1.25	1.21	1.01
2012	2.82	1.92	1.70	1.63	1.60	1.23
2012-1982	0.61	0.36	0.33	0.38	0.39	0.22

How did unit input costs change over time?

- Unit costs increased more for smallest farms

  $0.33-$0.39 for farms with more than 100 acres

  $0.61 for farms with less than 100 acres

- Divergence due to labor and variable inputs
  - New technologies did not lower these input costs as much for smallest farms
  - Lower adoption rates on small farms