Innovation and Climate Induced Yield Volatilities

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Why Does Yield Volatility Matter?

Consider your income.

- Assume that it varies 20% from year-to-year; would that matter?
- Would it matter if you didn’t know what it was going to be other than somewhere between 80% and 120%?
- Would it matter if you did not know how much it would vary?
- Would you handle an income realization of 120% differently than 80%?

Income volatility matters and lower versus upper tail realizations can have very different economic implications.
Do we Care about Yield Volatility?

- In 2014, Canada spent almost $1.4 billion on BRM subsidies and the US spent $6.2 billion on crop insurance subsidies.
- FPT Agricultural Ministers meeting earlier this month on the new policy framework - Minister Leal stated “...there needs to be a fundamental review of business risk management across Canada”.
This talk will look at how year-to-year yield volatility has changed through time and how that change has been influenced by both changing technology and changing climate.
Example

![Graph showing yield volatility with marginal density of precipitation](image)
Outline

1. Motivation
2. Yields in Ontario
3. Yield Volatilities
4. Yield Volatilities, Climate, Innovation
5. Summary
Challenge: safe and secure food supply at reasonable and stable prices

(Possible) Circumstances:

- increasing population
- evolving preferences (↑ meat demand)
- increasing demand for non-food ag products (biofuels)
- uncertain future climate (adaptation to unknowns)
- ... other

Degree of difficulty will be determined in large part by innovation
impressive gains in crop productivity (e.g. Duvick, 1977; Duvick and Cassman, 1999; Cassman, 1999; Hafner, 2003; Lobell, Schlenker, and Costa-Roberts, 2011; Ray et al., 2012)

yet persistent concerns of flat or declining yields... at best diminishing marginal returns (e.g. Hazell, 1984; Ladha et al., 2003; Peng et al., 2004; Brisson et al., 2010; Finger, 2010; Lin and Huybers, 2012; Ort and Long, 2014)

year-to-year yield volatility and the effects of climate and innovation on that yield volatility are equally important but has received less attention.
Economic Implications: Production Risk

**Developing World**
- Lack of effective risk management major impediment to economic and social development
- Karlan et al. (2014, *QJE*) more important than credit and liquidity constraints

**Developed World**
- Multiperil crop insurance predominant means of production risk management (heavily subsidized)
- Over last decade $\sim$ $60B federal government premium subsidies in US
**Corn Yield Distribution through Time**

![Graph showing corn yield distribution through time](image)

- 1970
- 1990
- 2010
Corn Yield Distribution through Time

Density

Yield (bushel/acre)

- 1970
- 1990
- 2010
Soybean Yield Distribution through Time

Yield (bushel/acre)
Soybean Yield Distribution through Time

Density

Yield (bushel/acre)

- 1970
- 1990
- 2010

Ker

Yield Volatility

May 2017
Wheat Yield Distribution through Time

Density

Yield (bushel/acre)

- 1970
- 1990
- 2010
Wheat Yield Distribution through Time

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Yield (bushel/acre) vs. Density

- 1970
- 1990
- 2010
Summarizing Ontario Crop Yield Distributions through Time

- county yield data from OMAFRA
- average yields are increasing through time
- yield volatility is increasing through time
- *yield volatility is increasing asymmetrically* - *greater increases in volatilities in the lower tail of the yield distribution.*
- lower tail is lagging behind the upper and middle parts of the yield distribution
Again, Why Does This Matter?

Just consider all the public monies funnelled into BRM programs in developing countries.
A Closer Look at the Asymmetric Nature of Changing Yield Volatilities

Corn

- 23 of 32 counties (72%) in Ontario show greater increases in lower tail volatility
- 370 of 472 US counties (78%) show greater increases in lower tail volatility
- 10 of the 11 counties (91%) that are statistically significant in the lower tail.
- 135 of the 142 (95%) counties that are statistically significant in the lower tail.
A Closer Look at the Asymmetric Nature of Changing Yield Volatilities

Soybean

- 6 of 6 counties in Ontario show greater increases in lower tail volatility
- 357 of 469 US counties (76%) show greater increases in lower tail volatility
- 3 of the 3 counties that are statistically significant in the lower tail.
- 126 of the 134 counties (94%) that are statistically significant in the lower tail.
A Closer Look at the Asymmetric Nature of Changing Yield Volatilities

**Wheat**

- 21 of 26 counties in Ontario show greater increases in lower tail volatility
- 142 of 225 US counties (63%) show greater increases in lower tail volatility
- 6 of the 6 counties (81%) that are statistically significant in the lower tail.
- 18 of the 27 counties (67%) that are statistically significant in the lower tail.
If we wrongly assume the yield volatility is increasing symmetrically through time (as commonly done) we can underestimate the actuarially fair premium rates for BRM, preliminary estimates are roughly 0-20% depending on crop, area, coverage level.
Yield Data

- Ontario county yield data - OMAFRA
- US county yield data - NASS
Climate Data

- Iowa and Ontario only right now
- derive growing season agronomic metrics
- based on daily precipitation, min and max temperature
- US Source: National Oceanic and Atmospheric Administration
- Ontario Source: Environment Canada
- weather station data interpolated to county centroids
  McKenney et al. (2011).
- agronomic metrics
  - GDD and HDD (Schlenker and Roberts, 2009, *PNAS*)
  - VPD (Roberts, Schlenker, and Eyer, 2012, *AJAE*)
  - Precipitation (PCP)
  - $\text{VPD}_{ja}$ and $\text{PCP}_{ja}$ during July-August (differential effects)
Lobell and Asner (2003a, *Science*) methodology:

- innovations have induced higher yield volatility
- in Iowa, changing climate explains roughly 24% of the spatial variation in overall volatility; 25% of the spatial variation in *lower* volatility; and 13% of the spatial variation in *upper* volatility
- in Ontario, changing climate explains roughly 19% of the spatial variation in overall volatility; 24% of the spatial variation in *lower* volatility; and 10% of the spatial variation in *upper* volatility
in Iowa, changing climate is estimated to be decreasing overall yield volatility growth by about 26% and thus innovation accounts for greater than 100% of the growth.

in Ontario, changing climate and innovation is estimated to account for 3% and 97% of the growth in yield volatility, respectfully.

need to expand the analysis to get more confidence in the empirical results, the number of counties is too small.
Contributions of Climate and Innovation to Volatility: Iowa Soybean

- constant coefficients are positive and significant indicating that innovations have induced higher yield volatility
- changing climate explains roughly 31% of the spatial variation in overall volatility; 31% of the spatial variation in lower volatility; and 16% of the spatial variation in upper volatility.
- changing climate and technology are estimated to account for 29% and 71% of the growth in yield volatility, respectfully

need to expand the analysis to get more confidence in the empirical results, the number of counties is too small.
Implications for Premium Rates: Corn

**huron**

- Rate as bushels per acre
- Rate as percent of guarantee

Actuarially Fair Premium Rate

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Implications for Premium Rates: Corn

- Rate as bushels per acre
- Rate as percent of guarantee
Solvency of Ontario’s AgrilInsurance Program under Changing Climate

We simulated a number of scenarios plausible and less so.

- steadily increased the probability of a low yield outcome
- increased volatility
- decreased technological change
- etc.

Essentially, because of the the experience-based rating system and how quickly losses are dissolved into future rates, the program will maintain its solvency.
Bigger issue is the design of yield or revenue insurance that provides appropriate risk coverage without incentivizing on-farm adoption of risky practices. It can make economic sense for producers to adopt high risk high reward technologies at the expense of less risky technologies under subsidized crop insurance.
Summary of Findings

- average yields are increasing through time
- year-to-year yield volatilities are increasing through time
- yield volatilities are increasing asymmetrically - more in the lower tail
- innovation accounts for the majority of the increases in yield volatility
- changing climate accounts for 20-25% of the spatial variation in yield volatility for Iowa and Ontario corn and Iowa soybean
- changing climate accounts for double the spatial variation in lower versus upper tail volatilities
- changing climate is estimated to be decreasing corn yield volatility in Iowa but increasing it in Ontario.
- changing climate is estimated to be increasing soybean yield volatility
Summary of Findings

- results are very region-crop specific; can not generalize
- actuarially fair premium rates will continue to increase in absolute value
- assuming increases in average yields outpace increases in lower tail volatilities premium rates will slightly decrease in terms of total liability or guarantee
- given the current experienced based rating structure, BRM program will remain solvent

I concentrated on year-to-year yield volatilities today. If you are interested on the effects of climate and innovation on the probability of low yield or average yields or any quantile in the yield distribution, see me after.
Thank You

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References II


