Evidence on the Private-Excess Fertilization Hypothesis

Yuyuan Che
Department of Agricultural, Food, and Resource Economics
Michigan State University
Email: cheyuyua@msu.edu

Hongli Feng
Department of Agricultural, Food, and Resource Economics
Michigan State University
Email: hennes65@msu.edu

David A. Hennessy
Department of Agricultural, Food, and Resource Economics
Michigan State University
Email: hennes64@msu.edu

Chaoqun Lu
Department of Ecology, Evolution, and Organismal Biology
Iowa State University
Email: clu@iastate.edu

Selected Poster prepared for presentation at the 2020 Agricultural & Applied Economics Association Annual Meeting, Kansas City, MO
July 26-28, 2020

Evidence on the Private-Excess Fertilization Hypothesis

Yuyuan Che[1], Hongli Feng[2], David A. Hennessy[3], Chaoqun Lu[4]

[1]Ph.D. Student, [2]Associate Professor, [3]Professor and Elton R. Smith Chair of Food & Agricultural Policy
Department of Agricultural, Food & Resource Economics, Michigan State University
[4]Assistant Professor, Department of Ecology, Evolution, and Organismal Biology, Iowa State University

MICHIGAN STATE UNIVERSITY

IOWA STATE UNIVERSITY

Motivation

Nitrogen (N) fertilizer use rates in U.S. corn production have had an overall increasing trend since 1970 (Figure 1), while some variation appears at both temporal and spatial dimensions (Figure 2). Corn yield response to nitrogen fertilizer use rate depends on soil attributes, weather conditions, and other factors.

Nitrogen discharges into rivers and then large water bodies have implications for ecological outcomes, amenity quality, local public finance and public health throughout the world (Breitburg et al. 2018). Many believe that farmers use more fertilizer than needed to maximize profitability (e.g., Agarwal et al. 2016), the excess nitrogen being deposited into the natural environment.

However, assessing the validity of these beliefs is difficult as the effectiveness of nutrient inputs varies with soils, weather and their interactions. Empirically little is known about whether nutrients are applied beyond the level that maximize a farmer's expected profit. This knowledge gap arises largely because limited crop-specific nutrient use data are available at sub-national levels of disaggregation.

The main purposes of this paper are to investigate whether nitrogen fertilizer use exceeds the privately optimal level, and what factors affect farmer choices on nitrogen fertilizer use rate which further influences nitrogen use efficiency (NUE).

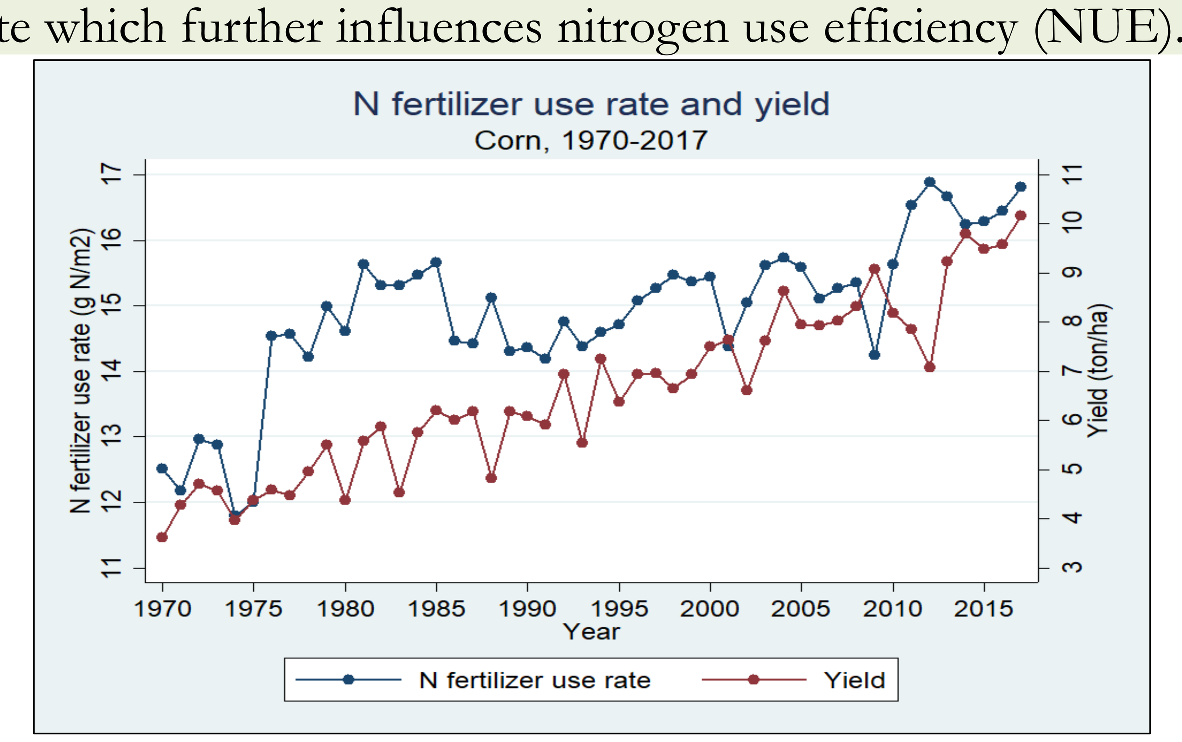

Figure 1. Nitrogen fertilizer use rate and yield in U.S. (Corn, 1970-2017)

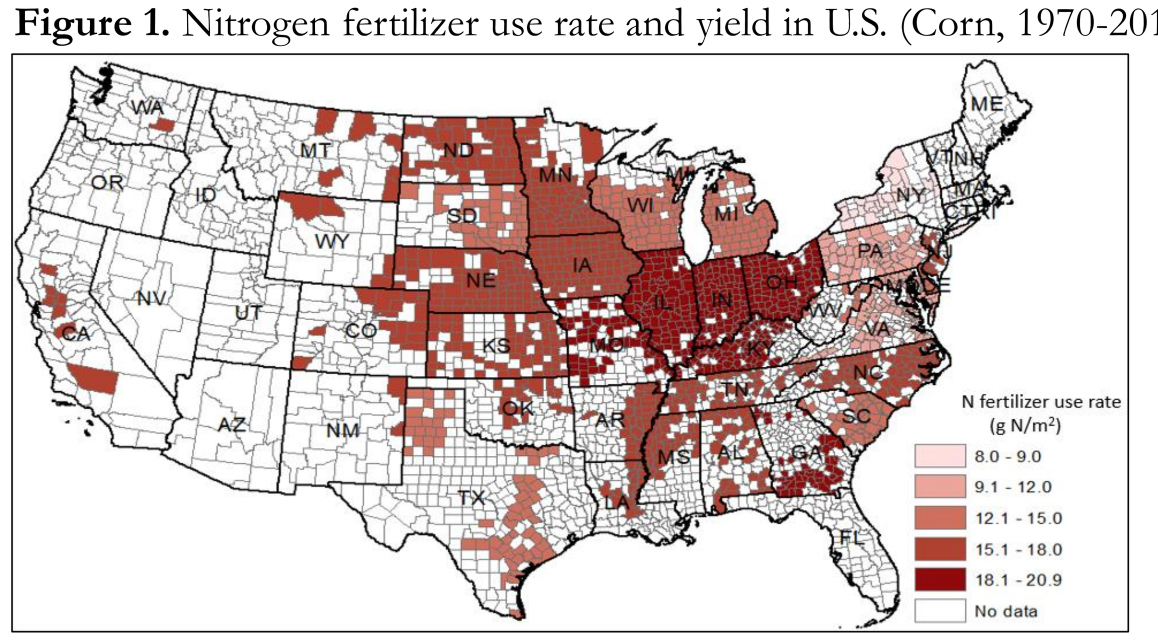

Figure 2. Distribution of nitrogen fertilizer use rate (Corn, 2015)

Data

Nitrogen and crop data

- Cao et al. (2018) and Lu et al. (2019) have developed and validated a multi-decadal panel data of nitrogen application rates, nitrogen use efficiency, and crop yields for corn in the United States over 1970-2017.
- Crop trials data provides corn yields at different nitrogen application levels in Floyd County, Iowa over 1979-2003.

Price data

- U.S. Department of Agriculture Economic Research Service provides nitrogen producer price indexes and selected fertilizer prices.
- Corn futures prices are obtained from Chicago Mercantile Exchange.
- Natural gas prices are from the U.S. Department of Energy, Energy Information Agency.

Weather and soil data

- National Oceanic & Atmospheric Administration files provide weather data, which are transformed into annual county-level growing degree day (GDD), stress degree days (SDD) and severe-to-extreme dryness (Palmer Z≤-2, DryPZ) and severe-to-extreme wetness (Palmer Z≥2.5, WetPZ).
- Soil attribute data are from National Resource Inventory files.

Research Methods

Profit maximization focusing on nitrogen use rate

- Profit function is $\pi(N,\theta) = py(N,\theta) - wN - C$, (1)
  where *N* represent nitrogen fertilizer use rate. Crop yield is given as $y(N,\theta)$ on $N \in \bar{\mathbb{R}}_{+}$, the closed set of non-negative reals, and θ indicates all other inputs. The yield function is assumed to have standard properties. Crop price is *p*, nutrient price is *w* and all other costs are *C*.
- The first-order optimality condition is $py_N(N,\theta) - w = 0$, (2)
  where subscript represents appropriate derivative, and with solution N^*.
- Defining $\varepsilon \equiv (p/w)y_N(N,\theta)$, then $\varepsilon = 1$ occurs when marginal value of output equals marginal costs. When $\varepsilon|_{N=N^*} < 1$ (respectively >1) then nitrogen use exceeds (is below) its expected profit maximizing level. We estimate ε by using crop trials data and nitrogen panel data.

How does nitrogen use rate respond to prices and weather factors

- **A two-stage least squares estimation:**

$$\hat{P}_{c,t} = \gamma_0 + \gamma_1 G_{c,t} + \gamma_2 t + \gamma_3 F_{c,t} + \gamma_4 W_{c,t};$$
$$N_{c,t} = f(\hat{P}_{c,t}, t, F_{c,t}, W_{c,t}) + \eta_{c,t}. \quad (3)$$

  where c is county, t is year, $P_{c,t}$ is nitrogen price, $G_{c,t}$ is natural gas price, $F_{c,t}$ is corn futures price, $W_{c,t}$ is weather and soil vector, $N_{c,t}$ is nitrogen fertilizer use rate.
- **Instrument:**
  Nitrogen prices are endogenous to agricultural market conditions, so we apply natural gas prices to instrument. Natural gas is the most important input in nitrogen production, but prices are determined by world energy markets and not by agricultural markets.

Results & Discussion

$\varepsilon \equiv (p/w)y_N(N,\theta)$ can be calculated with $\widehat{y_N}$ from crop trials data, corn futures price (adjusted to 90% due to basis), nitrogen prices, N fertilizer use and yield data. Table 1 shows how yield responds to N fertilizer use for two rotation types in Floyd County, Iowa, that additional N fertilizer application has a greater yield response for corn-corn rotation than that for corn-soybean rotation, since soybean can fix nitrogen in soil. The epsilon trendlines (Figure 3) show that N fertilizer use rates at 160 lb/A and 220 lb/A are lower than the private optimum for corn-corn rotation for most years, while these two N fertilizer levels exceed the private optimum for corn-soybean rotation in recent years.

Econometric analysis (Table 2) shows that a higher nitrogen price would reduce farmers' N fertilizer use rate, while a greater crop price would encourage N fertilizer use. These prices further affect nitrogen use efficiency through the channel of N fertilizer use rate, since greater N fertilizer use rate would decrease nitrogen use efficiency. Moreover, weather and soil conditions would affect both N fertilizer use rate and efficiency.

This work is in progress. More is needed to further investigate whether farmers overuse nitrogen and what factors affect N fertilizer use and efficiency. This is useful because it would help to seek ways to adjust nutrient application to the privately optimal level if farmers are overusing fertilizer, otherwise, farmers may keep the current fertilizer use rate under the profit maximization level due to environmental externalities of additional fertilization.

Table 2. Estimation results of N fertilizer use rate and NUE

VARIABLES	N fertilizer use rate(2SLS)		NUE (OLS)	
Nitrogen price	-8.515[a]	-1.637[a]		
Corn futures price	79.40[a]	22.46[a]		
N fertilizer use rate			-0.0208[a]	-0.0248[a]
GDD	0.00301[a]	-6.77e-05	-0.000141[a]	1.64e-05[a]
SDD	0.00260[a]	-0.000344	-0.000120[a]	-0.00131[a]
DryPZ	-1.071[a]	-1.566[a]	0.144[a]	-0.00706
WetPZ	0.136	1.303[a]	-0.143[a]	-0.138[a]
GDD × DryPZ	0.000179	0.00125[a]	-0.000216[a]	-0.000102[a]
GDD × WetPZ	-0.000353[c]	-0.000990[a]	7.41e-05[a]	5.55e-05[a]
SDD × DryPZ	0.00478[a]	-0.00198[a]	0.000713[a]	0.000843[a]
SDD × WetPZ	0.00550[a]	0.00135	0.00121[a]	0.000520[a]
LCC I&II	1.207[a]		0.113[a]	
year	0.150[a]	0.0643[a]	0.00622[a]	0.00602[a]
Indicator (year≥1976)	2.564[a]	2.182[a]		
County FE	No	Yes	No	Yes
Observations	85,576	85,551	85,576	85,551
R-squared	0.119	0.247	0.392	0.726

[a] p<0.01, [b] p<0.05, [c] p<0.1

Table 1. Corn yield responses to N fertilizer use rate in Floyd County, Iowa

Rotation types	Corn-Corn	Corn-Soybean
Variables	Log (Yield)	Log (Yield)
Log (N fertilizer use rate)	0.235[a]	0.0799[b]
Constant	3.621[a]	4.591[a]
Observations	225	225
R-squared	0.150	0.027

[a] p<0.01, [b] p<0.05, [c] p<0.1

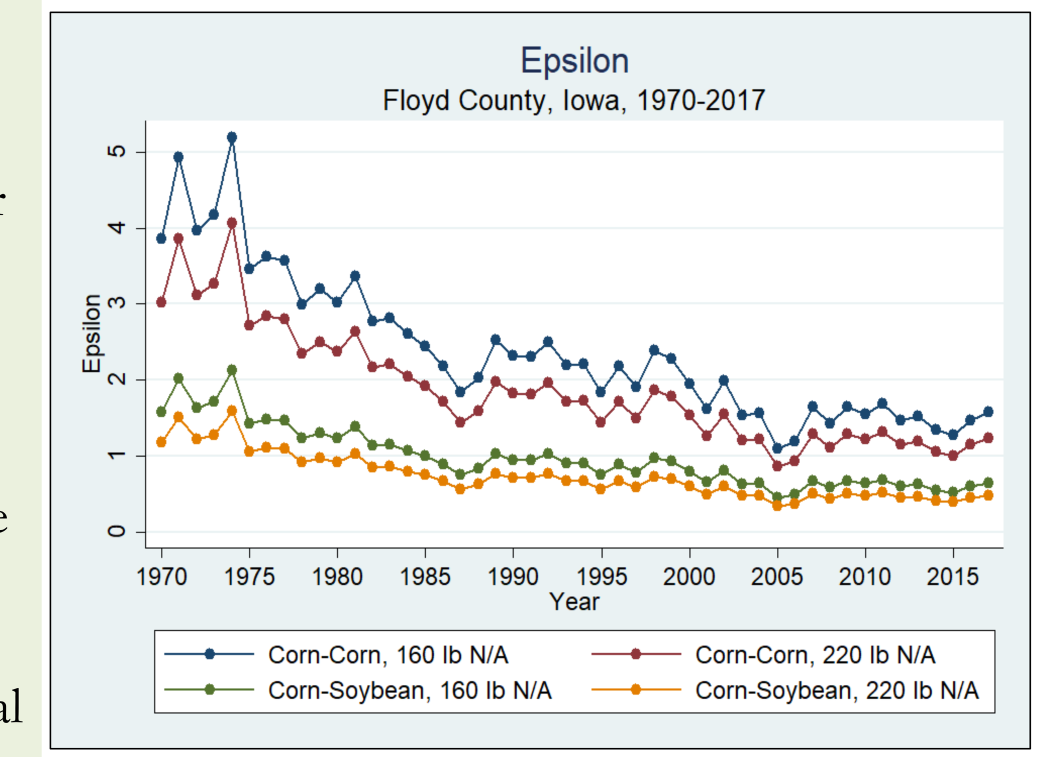

Figure 3. Trend lines of epsilon at different N fertilizer use rates by rotation type in Floyd County, Iowa over 1970-2017

References

Agarwal S, et al. 2016. Unfolding the bias in farm nitrogen management. Selected Paper, 2016 AAEA Annual Meeting, Boston, Massachusetts, July 31-August 2.

Breitburg D, et al. 2018. Declining oxygen in the global ocean and coastal waters. Science, 05 Jan, 359(6371), DOI: 10.1126/science.aam7240.

Cao P, et al. 2018. Historical nitrogen fertilizer use in agricultural ecosystems of the contiguous United States during 1850–2015: application rate, timing, and fertilizer types. Earth System Sci. Data, 10(2), 969-984.

Lu C, et al. 2019. Are we getting better in using nitrogen?: Variations in nitrogen use efficiency of two cereal crops across the United States. Earth's Future, 7(8), 939-952.