Environmental Stress, Genetic Engineering, and Agricultural Productivity

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Motivation

Background

- 92% of corn planted acres in the US were transgenic by 2020 since the first commercial use of genetically engineered (GE) seeds in 1996.
- Ground-level ozone, a major source of environmental stresses in addition to climate change, has been identified as a hidden threat to U.S. agriculture.
- However, to the best of our knowledge, there have been no studies that consider the role of genetically engineered (GE) crops in understanding how ozone concentrations impact yields and yield risks.

Research Questions

- How do ozone influence crop average yields and yield risks when genetic engineering is involved?
- Does agricultural genetic engineering either help or damage crops' ability to deal with environmental stress from ozone?

Empirical Model

Two-way fixed effects model

$$log(y_{ct}) = \alpha_1 Ozone_{ct} + \alpha_2 GE_{ct} + \lambda Ozone_{ct} \times GE_{ct} + \boldsymbol{W}_{ct}\beta + \delta_c + \theta_t + \varepsilon_{ct} \quad (1)$$

- $log(y_{ct})$: log of corn yield (Bushel/Acre) in county c and year t
- $Ozone_{ct}$: growing season average of ozone in county c and year t
- GE_{ct}: GE seed adoption rate in county c and year t
- $Ozone_{ct} \times GE_{ct}$: interaction term; W_{ct}: weather controls
- δ_c : county FE; θ_t: year FE; ε_{ct}: idiosyncratic error term

Farmers care not only about crop yields, but also about the yield risks to which they are exposed. Referring to Antle (1987 *AJAE*) and Cisse and Barrett (2018 *JDE*), we adopt a moment-based approach to measure risk exposure.

Motivation to instrument ozone

- Possible systematic measurement error of remote sensing data (Alix-Garcia & Millimet, 2021)
- Emissions of precursors from agricultural machinery, fertilizer use, tilling

2SLS estimation

Instrument focal ground-level ozone with upwind ozone inspired by Bayer et al. (2009 *JEEM*)

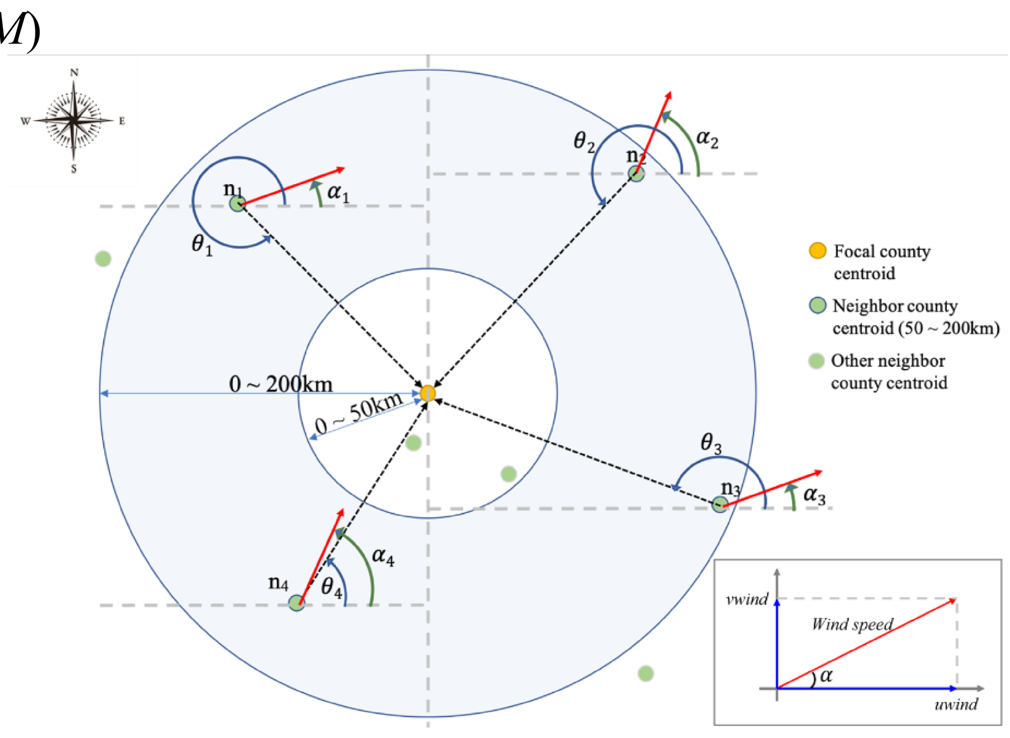

Figure 1. Illustration on how to calculate IV

Note: The yellow point represents the focal county centroid. The green points in the 50-200km buffer zone are source counties when calculating upwind ozone concentrations. The green points not in the 50-200km buffer zone are counties that are not considered when calculating upwind ozone concentrations. The red arrow represents the wind direction.

Data

This research compiled several datasets and finally constructed a county-level dataset with around 2260 counties for the years 2003 to 2020.

- Yield data: NASS-USDA
- Ozone data: Remote sensing data from EAC4-European Center for Medium-Range Weather Forecast (baseline); EPA data (robustness)
- GE adoption data: survey data from *dmrk* (baseline); ERS-USDA (robustness)
- Weather data: CAMS-ECMWF
- Growing season data: NASS-USDA

Results I: Yield Effects

Table 1. Effects of ozone and GM adoption on crop yields

	(1)	(2)	(3)	(4)	(5)
Dependent var.	Log of yield (Bushel/acre)				
Model	Two-way fixed effects			TWFE with IV	
Ozone		-0.0243***	-0.0283***	-0.0285***	-0.0303***
		(0.0020)	(0.0034)	(0.0037)	(0.0098)
Ozone*log of GM			-0.0153***		-0.0145**
			(0.0040)		(0.0071)
Log of GM			0.5440***		0.5092*
			(0.1584)		(0.2703)
GDD8,32(X1000)	0.4516***	0.6281***	0.9079***	0.6593***	0.9289***
	(0.1452)	(0.1372)	(0.2121)	(0.1474)	(0.2235)
GDD8,32 squared	-0.1137***	-0.1292***	-0.1874***	-0.1319***	-0.1894***
	(0.0280)	(0.0269)	(0.0408)	(0.0277)	(0.0412)
Square root of GDD32+	-0.0967***	-0.0850***	-0.0978**	-0.0830***	-0.0966**
	(0.0243)	(0.0229)	(0.0411)	(0.0227)	(0.0408)
Precipitation	0.2349***	0.1974***	0.1239***	0.1908***	0.1221***
	(0.0337)	(0.0324)	(0.0420)	(0.0331)	(0.0436)
Precipitation squared	-0.0234***	-0.0230***	-0.0144**	-0.0229***	-0.0145**
	(0.0051)	(0.0049)	(0.0066)	(0.0049)	(0.0065)
Wind speed	-0.1765***	-0.2135***	-0.2331***	-0.2201***	-0.2398***
	(0.0297)	(0.0312)	(0.0398)	(0.0322)	(0.0432)
County FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Adjusted R2	0.323	0.343	0.383	-	-
KP F-statistics	-	-	-	409.979	49.277
Observations	29549	29549	21221	29549	21221

- One within-county SD ↑ of ozone ➔ 7.1% (≈2.85%*2.49) ↓ of corn yields.
- Omitting ozone could underestimate effects of $GDD_{8,32}$ and overestimate GDD_{32+}
- GE adoption has positive effects on crop yields (but marginally significant).
- GE adoption tends to amplify ozone's negative effects on yields.

Results II: Risk Effects

Table 2. Effects of ozone and GE adoption on yield risk patterns

	(1)	(2)	(3)	(4)
Dependent var.	Mean of log yield	Variance of log yield	Skewness of log yield	Kurtosis of log yield
Model	Two-way fixed effects with IV			
Ozone	-0.0303***	0.0091***	-0.0079**	0.0069**
	(0.0098)	(0.0033)	(0.0032)	(0.0028)
Ozone*log of GM	-0.0145**	0.0069***	-0.0066***	0.0052**
	(0.0071)	(0.0023)	(0.0022)	(0.0020)
Log of GM	0.5092*	-0.2545***	0.2468***	-0.1897**
	(0.2703)	(0.0871)	(0.0827)	(0.0767)
GDD8,32(X1000)	0.9289***	-0.1383**	0.0401	-0.1575**
	(0.2235)	(0.0627)	(0.0850)	(0.0620)
GDD8,32 squared	-0.1894***	0.0256***	0.0038	0.0219**
	(0.0412)	(0.0097)	(0.0140)	(0.0091)
Square root of GDD34+	-0.0966**	0.0239***	0.0036	0.0110
	(0.0408)	(0.0084)	(0.0146)	(0.0078)
Precipitation	0.1221***	0.0255	-0.0127	0.0267
	(0.0436)	(0.0191)	(0.0191)	(0.0191)
Precipitation squared	-0.0145**	-0.0042	0.0025	-0.0042
	(0.0065)	(0.0026)	(0.0027)	(0.0027)
Wind speed	-0.2398***	0.0502**	-0.0465**	0.0470**
	(0.0432)	(0.0216)	(0.0184)	(0.0183)
County FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
First-stage KP F-statistic	49.277			
Observations	21221	21221	21221	21221

- GE decreases the yield risk (variance), downside risk (skewness), and the likelihood of the rare events in the tails of corn yield distribution (kurtosis)
- Ozone increases the yield risk (variance), downside risk (skewness), and the likelihood of the rare events in the tails of corn yield distribution (kurtosis)
- GE amplifies ozone's risk-increasing effects, downside risk-increasing effects, and amplifies ozone's effects of increasing the likelihood of the rare events of corn yield distribution

Discussion

- Our results suggest the importance of detecting the trans-gene(s) that damage(s) crops' ability to cope with ozone and identifying molecular markers for ozone tolerance.
- Our results highlight the importance of breeding GE seeds that are resilient to environmental stress from ozone pollution in addition to existing traits.

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