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"Best Management Practices and Nutrient Reduction: An Integrated Economic-Hydrologic Model of the Western Lake Erie Basin" by Hongxing Liu, Wendong Zhang, Elena Irwin, Jeffrey Kast, Noel Aloysius, Jay Martin, and Margaret Kalcic

Appendix C: Construction and prediction of field-level BMP adoption costs

C.1 Construction of Field-level Production Cost

We calculate the total costs of managing the farm for each respondent based on their specific responses in the survey. In particular, each farmer was asked to allocate all their fields into high-, medium-, and low-productivity categories based on corn and soybean yield ranges and pick one field from a randomly selected quality class (e.g., pick one field among all high-productivity fields that they operate). For each chosen field, the farmer provided various field-specific expenditures that we used to construct the field-level production cost (see Appendix A for sample questions on these expenditures). These responses include field-specific seeding rate and seeding cost, manure quantity, type, and unit price, fertilizer application quantity, type, and unit price, per-acre expenditures on herbicide and federal crop insurance program, as well as whether the fields are cash rented from other farmers. The respondents also provided agricultural production details on corn drying, machinery usage and repairs, fuel usage, and labor and management conditions, which were converted into dollar-based expenditures using the statewide custom rates and standard production costs based on the 2012 Ohio State University Production Cost and Custom Rate Survey (Ward 2012).

C.2 Predicting Field-level Adoption Cost of Conversation Practice

Field-level adoption cost of specific conservation practices is one unique explanatory variable. For each practice—fertilizer subsurface placement or cover crops—we run a separate OLS regression of the field-level total production cost on field-level physical characteristics (e.g., field size, soil quality, rent status), management practice decisions (e.g., BMP adoption), and field operator's demographic characteristics (e.g., age). This regression allows us to separate the adoption cost for each conservation practice from its total production cost at the field level and allow for heterogeneity in this cost across fields and operators. We include two interaction terms between this adoption dummy—one operator demographic characteristic (age) and one field-level characteristic—proxied by field size. Previous literature has demonstrated that adoption cost will vary by both operator and field characteristics (Traoré, Landry, and Amara 1998; Prokopy et al. 2008). We use the age of the operator and field size as two proxies for this heterogeneity. We represent the field size in both acreage and acreage bins and find robust results.[i] In particular, we estimate two regressions for phosphorus fertilizer subsurface placement and cover crop adoption separately:

$$\begin{aligned}\textit{Field level total production cost} &= \alpha * \mathrm{X_{field}} + \beta * \mathrm{X_{operator}} + \gamma_1 * \text{already adopted subsurface placement} + \gamma_2 \\ &* \text{already adopted subsurface placement} * \text{age} + \gamma_3 * \text{already adopted subsurface placement} \\ &* \text{acreage} + \gamma_4 * \text{adopted any BMP other than subsurface placement} \\ &+ \varepsilon \qquad \text{Eq. [C1]}\end{aligned}$$

$$\begin{aligned}\textit{Field level total production cost} &= \zeta * \mathrm{X_{field}} + \eta * \mathrm{X_{operator}} + \theta_1 * \text{already adopted cover crops} + \theta_2 \\ &* \text{already adopted cover crops} * \text{age} + \theta_3 * \text{already adopted covercrops} * \text{acreage} + \theta_4 \\ &* \text{adopted any BMP other than cover crops} + \varepsilon \qquad \text{Eq. [C2]}\end{aligned}$$

where $\mathrm{X_{field}}$ includes field size, soil quality, whether the field is rented (0/1), and whether the field has adopted any BMP other than subsurface placement (0/1); and, $\mathrm{X_{operator}}$ includes the age of the farmer. In particular, as explained earlier, we included a binary variable "already adopted," which equals one when the farmer has already adopted the BMP of interest on this specific field. We also control for the adoption of BMPs other than the one of interest including grid soil sampling with variable rate, delaying broadcasting when the forecast predicts a 50% or more chance of at least one inch of total rainfall in the next 12 hours, managing field water levels with drainage management systems, avoiding winter or frozen ground surface application of phosphorus, avoiding fall application of phosphorus, determining rates based on regular soil testing once within the rotation (or every three years), following soil test trends to maintain the agronomic range for phosphorus in the soil (15 to 30 ppm), and requiring a 4R certification program for private applicators.

In practice, the adoption dummy variable and these two interaction variables allow us to derive field-specific adoption costs after estimating these two aforementioned regressions:

$$\text{Field level predicted adoption cost for field i for subsurface placement} = \widehat{\gamma}_1 * \text{already adopted subsurface placement} + \widehat{\gamma}_2 * \text{already adopted subsurface placement} * \text{age\_i} + \widehat{\gamma}_3 * \text{already adopted subsurface placement} * \text{field size\_i} \quad \text{Eq. [C3]}$$

$$\text{Field level predicted adoption cost for field i for cover crops} = \widehat{\theta}_1 * \text{already adopted cover crops} + \widehat{\theta}_2 * \text{already adopted cover crops} * \text{age}_i + \widehat{\theta}_3 * \text{already adopted cover crops} * \text{field size}_i \quad \text{Eq. [C4]}$$

where $\widehat{\gamma_0}, \widehat{\gamma_1}, \widehat{\gamma_2}, \widehat{\gamma_3}, \widehat{\theta_0}, \widehat{\theta_1}, \widehat{\theta_2}, and\ \widehat{\theta_3}$ are coefficients estimated from Eq. [C1] and Eq. [C2].

These regressions naturally suggest that in our study, the adoption costs for BMPs vary not only by the intrinsic features of BMP adoption ($\widehat{\gamma_0}, \widehat{\gamma_1}, \widehat{\theta_0}$, and $\widehat{\theta_1}$), but also vary across different fields and farmers due to heterogeneous age/experience and spatially-varying field characteristics. We expect $\widehat{\gamma_1} and\ \widehat{\theta_1}$ to be postitive, representing an increase in production cost in general due to BMP adoption, but $\widehat{\gamma_2}$ and $\widehat{\theta_2}$ to be negative meaning that more experienced operators could adopt these practices in a marginally more cost-effective manner. $\widehat{\gamma_3}$ and $\widehat{\theta_3}$ can be positive or negative depending on the particular BMP because some larger fields have lower per acre costs due to economies of scale, while some other larger fields require different technology or crops that potentially increase per acre costs.

C.3 Predicting Field-level Adoption Cost of Conversation Practice

We estimate Eq. [C1] to predict field-level adoption costs of subsurface placement. Table B.1 shows that on average the cost of adopting any BMP other than subsurface placement is $24 per acre. Larger farms and better soil quality induce higher production cost, which may be interpreted as higher investment on the farm. Rented land also incurs higher associated costs. Our approach allows us to dissect the farm-specific adoption cost of BMP based on farmer demographic characteristics (represented by farmer's age) and farm-level physical characteristics (represented by field size). As predicted, we find $\widehat{\gamma_1}$ to be positive, showing there is additional cost of adopting subsurface placement. $\widehat{\gamma_2}\ and\ \widehat{\gamma_3}$ are both negative, indicating that farmer experience and economy of scale reduces the per acre adoption cost. For those who adopted subsurface placement, the adoption cost decreases by $1 per acre ($\widehat{\gamma_2}$) with a one-year increase in farmer's age; and, a one-acre increase in field size decreases the adoption costs by about $.28 ($\widehat{\gamma_3}$). Based on these estimates, we uncover the field- and farmer-specific subsurface placement adoption cost following Eq. [C3]:

$$subsuface\ placement\ adoption\ cost = 102.3464 - 1.0503 * age - 0.2828 * field\ acreage \qquad Eq.[C5]$$

We set the lower bound of adoption cost at zero and replace those below zero with zero because it is unrealistic to assume a negative adoption cost, which accounts for less than the lowest 5% tail of the distribution. The average estimated per acre subsurface placement adoption cost is $24.32 based on average farmer characteristics and field-level characteristics, which is in line with BMP adoption cost, and different federal or state cost-share programs. Generally, subsurface placement is $12–$15 more per acre than broadcast phosphorus application, where broadcasting costs $4.10 – $15.20 per acre depending on the fertilizer type. For non-adopters, we assume their costs are higher and use the 75th percentile ($100.07/acre) of the adoption cost distribution as the proxy.

Table C.1. Subsurface Placement Adoption Cost Estimates

Variable	Total cost	
	Field acreage	Field acreage bins
Other_BMP	23.7767***	25.6974***
	(7.228)	(7.253)
Field_acre	0.2821***	
	(0.058)	
Field_size_bin_dummy		32.3665**
		(12.677)
Age	-0.2244	-0.2329
	(0.212)	(0.213)
Soil_quality	27.6678***	28.4730***
	(3.446)	(3.460)
Field_rent	14.1109**	14.4501**
	(6.013)	(6.039)
Already_placement($\widehat{\gamma_0}$)	102.3464***	127.7725***
	(26.584)	(33.620)
Already_placement*age ($\widehat{\gamma_1}$)	-1.0503**	-1.0638**
	(0.440)	(0.442)
Already_placement*field acreage($\widehat{\gamma_2}$)	-0.2828***	
	(0.058)	

Already_placement* Field_size_bin_dummy ($\widehat{\gamma_2}$)		-37.0227*
		(20.424)
Constant	242.5131***	218.3774***
	(62.212)	(64.200)
Fixed effect	County level	County level
Observations	2,324	2,324

The results for cover crops resemble that for subsurface placement (Table B.2), and similarly, wee uncover the field- and farmer-specific cover crop adoption cost following Eq. [C4]:

$$cover\ crop\ adoption\ cost = 38.8825 - 1.0555 * age + 0.2957 * field\ acreage \qquad Eq.[C6]$$

As expected, we find $\widehat{\theta_1}$ to be positive, showing the additional cost of adopting cover crops. We find $\widehat{\theta_2}$ to be negative, indicating one year of experience reduces the adoption costs by about $1. Here we find adoption cost increases with field size, which could be explained by the different types of cover crops or different technology chosen due to the field size. Using these proxies, we find that the average per acre adoption cost for cover crops is $31.70, which is in the range of USDA-NRCS payments ($28.71/acre to $34.76/acre).[ii] Again, for non-adopters, we assume their costs are higher and use the 75th percentile ($36.60/acre) as a proxy for their adoption costs.

Table C.2. Cover Crops Adoption Cost Estimates

Variable	Total cost	
	Farm acreage	Farm acreage bins
Other_BMP	38.3383***	38.4771***
	()	(6.87)
Field_acre	-0.0007	
	(.002)	
Field_size_bin_dummy		21.3790*
		-11.072
Age	-0.3167	-0.3396*
	(0.198)	(0.198)

Soil_quality	27.5982***	27.9594***
	(3.488)	(3.486)
Field_rent	13.6962**	13.7392**
	(6.077)	(6.083)
Already_cover_crop($\widehat{\theta_0}$)	38.8825	73.2262
	(36.938)	(44.877)
Already_cover_crop*age ($\widehat{\theta_1}$)	-1.0555*	-1.1383*
	-0.614	-0.613
Already_cover_crop*acreage($\widehat{\theta_2}$)	0.2957**	
	-0.13	
Already_cover_crop* Field_size_bin_dummy		-14.4433
		-44.877
Constant	272.0461***	246.7916***
	-61.978	-63.363
Fixed effect	County level	County level
Observations	2,324	2,324

[i] 150 acres each bin

[ii] https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1082778.pdf