The Impact of Soil Erosion on Agricultural Land Values in the US Midwest

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Abstract

This study examines the impact of soil erosion levels on agricultural land values in the United States (US) Midwest. Based on a novel county-level panel data set with information on soil erosion levels and agricultural land values, we investigate the direct effect of two types of soil erosion – water and/or wind erosion – on agricultural land values. Linear panel fixed effects econometric models, a recently developed "external-instrument-free" estimation approach, and a number of robustness checks are used to achieve the study objective. We find that increasing soil erosion levels has a statistically significant negative impact on agricultural land values at the county-level. Our findings confirm that damages to the soil from water or wind erosion are capitalized into lower farmland values. For instance, we find that a 1% increase in soil loss due to water erosion (in tons per acre) can lead to $235.87 per acre reduction in agricultural land value. The study also provides new insights in terms of further understanding the economic damages due to soil erosion, and the likely benefits from soil erosion control.

Keywords: Soil Erosion, Agricultural Land Values, Fixed Effects, Panel Data
JEL Codes: Q15, Q18, Q24, Q54

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1 Introduction

Agricultural land is an important economic asset, and it plays a unique role in agricultural production. In general, agricultural land values are determined by, among other factors, expectations of future income, which are themselves related to the productive capacity of the soil and expected economic returns from agricultural production (Borchers et al., 2014; Reydon et al., 2014; Telles et al., 2016, 2018). Therefore, soil conditions and fertility levels may affect agricultural land values, either through the rental rate or the sale price of the agricultural land (Chen et al., 2022a). In recent years, soil erosion has been widely considered to be one of the most serious threats to the long-term viability of agriculture worldwide (Pimentel, 2006; Eaton, 1996). Nearly one-third of the world's cultivable land has been lost due to soil erosion, resulting in an estimated total loss of global productive land at 6.7 million ha (Pimentel et al., 1995; Komissarov and Ogura, 2020; DeLong et al., 2015). For the US, soil erosion is estimated to cost approximately $44.39 billion each year due to lost productivity (Crosson, 2007; Ellis et al., 2019; Sulaeman and Westhoff, 2020; Weeraratna, 2022).

The effects of soil erosion on agricultural land have been of particular concern as it affects soil health and, in turn, future agricultural productivity. Soil erosion involves the long-term breakdown, detachment, transport, and redistribution of soil particles by forces of water or wind. Both water and wind erosion reduce the water-holding capacity of the soil, which can result in water shortages that can severely affect crop productivity at critical stages of plant development (Buntley and Bell, 1976). Moreover, the decreased availability of soil organic matter and nutrients due to erosion also lead to reductions of cultivable soil depth and declines in soil fertility (Morgan, 2009). Therefore, continuous exposure to erosion makes the soil progressively less productive. This productivity decline reduces the land's capacity to produce food, decreases economic returns from agricultural production, and therefore likely affects agricultural land values (Chen et al., 2022a). Understanding the relationship between soil erosion level and agricultural land values is critical to quantifying the economic damages from soil erosion, and the potential benefits of practices that help control soil erosion control in farmer fields.

The objective of this study is to investigate the impact of soil erosion on agricultural land values in the United States (US) Midwest. To achieve this objective, we utilize unique county-level data for annual soil loss caused by erosion (tons/acre) from the National Resources Inventory (NRI) program of the US Department of Agriculture (USDA) Natural Resource Conservation Service (NRCS) for the following census years: 2002, 2007, 2012 and 2015. Then, we collect county-level data on agricultural land values from the USDA National Agricultural Statistics Service (NASS) for census years 2007, 2012 and 2017. We also utilize weather variables, government payments, and county population data collected from a variety of sources. The resulting panel dataset used in the study covers 645 counties over twelve states in the US Corn Belt for the years 2007 and 2012. Based on this panel dataset, we develop econometric models to analyze how soil loss due to erosion (i.e., from water, wind, or both) affect agricultural land values.

Given the potential effects of soil productivity on agricultural land values, there have been several studies that investigated the relationship between soil-conserving (or soil-productivity-enhancing) management practices and farmland values (Ervin and Mill, 1985; Gardner and Barrows, 1985; King and Sinden, 1988; Telles et al., 2018; Chen et al., 2022a). For example, a recent paper by Chen et al. (2022a) investigated the impact of a particular soil conservation practice (i.e., no-till systems) on agricultural land values in the US Midwest. Their results indicate that the economic and environmental benefits from adopting a soil health management technology like no-till are capitalized into higher farmland values. This result supports earlier studies that have found that adoption of soil conservation practices in general tends to have a positive influence on agricultural land values (King and Sinden, 1988; Telles et al., 2018).

Notwithstanding the relatively robust literature that links soil conservation practices and farmland values, there are fewer studies that explicitly examined the relationship between soil erosion levels and agricultural land values. One such study is by Duffy (2012) where the economic cost of soil erosion in Iowa was evaluated by considering the change in land value due to soil-erosion-induced reduction in soil fertility and the consequent decrease in yield potential. The potential change in Iowa land rental values because of soil erosion was also explored in Duffy (2012). Another paper that explored the potential impact of soil erosion on agricultural land values is Hertzler et al. (1985). In this study, the user cost of soil erosion was first estimated by considering how soil erosion reduces yields and increases operating costs over time, and then determined whether the higher user cost of soil erosion is capitalized into farmland values. They found that the productive value of farmland was significantly reduced by about $170 per acre because of soil erosion.

Our study contributes to the literature in a couple of ways. First, to the best of our knowledge, there has been no recent study that econometrically examined how soil erosion levels (i.e., specifically, the annual soil loss due to erosion) directly affect agricultural land values in the US Midwest. By carefully estimating the impact of soil loss due to major types of erosion on agricultural land values, our study provides new empirical evidence on whether the potential productivity loss due to soil erosion translate to decreases in agricultural land values. This economic cost of soil erosion to landowners has not been documented accurately in the context of agricultural production in the US Midwest. Moreover, many of the existing studies examining the economic damage of soil erosion to farmers are decades old and did not use recent econometric methods in the analysis.

Second, using unique county-level soil erosion data combined with the agricultural land value data set, this study econometrically examines the impact of soil erosion level on agricultural land values over a wider geographical region and over a longer time period compared to the previous literature. Given the geographic scope of the data set, we are able to investigate the aggregate county-level effects of soil erosion on land values in a major agricultural producing region of the US rather than estimating effects only for a specific location. Moreover, we also contribute to the literature by evaluating the effects of soil erosion on agricultural land values due to two particular causes — water and wind. The soil erosion data we have provides detailed information on soil loss caused by wind erosion and water erosion. This allows us to investigate how water-caused and wind-caused erosion separately (or combined) influence agricultural land values over time.

Findings from our study show that soil erosion has a statistically significant negative impact on agricultural land values, implying that counties with higher soil erosion levels tend to have lower farmland values. Specifically, our findings suggest that a 1% increase in water-caused soil erosion can lead to a decrease in agricultural land values by $235.87 per acre. We do not find a statistically significant wind erosion effect on farmland values. Last, taking both county-level water and wind soil erosion level into account, our estimates show that a 1% increase in the total soil erosion level can lead to a decrease in agricultural land values of $216.38 per acre for counties in the twelve US Midwest states utilized in our study.

The rest of this article is organized as follows. Section 2 provides a brief background about the economic effect of the soil erosion problem and describes potential mechanisms by which soil erosion effects can be capitalized into agricultural land values. Section 3 presents a detailed description of the data sources and our empirical approach. Section 4 provides a thorough discussion of the estimation results and provides various robustness checks. Lastly, implications, limitations, and future research directions are presented in the concluding section.

2 Background

2.1 The Economics of Soil Erosion

Soil erosion in the US has been a matter of public concern since the 1930s (Trimble and Crosson, 2000). In general, soil erosion can be defined as a form of soil degradation on agricultural land, and it pertains to the relatively rapid removal of topsoil by rain or wind. Soil deterioration and reduction in water quality due to soil erosion have become a serious problem for the productivity of agriculture and the environmental benefits from water resources (Al-Kaisi, 2000). Soil erosion is not only an environmental issue, the impacts of agricultural land degradation and the depletion of soil resources also result in significant economic costs for the US economy. Given the on-site effects of soil erosion on land productivity and the off-site environmental damage to the public and society, there are three major aspects related to the economic costs of soil erosion: (i) loss of crop yield productivity, (ii) added costs to farmers, and (iii) added costs to society.

The most important on-site effect of soil erosion is the loss of agricultural productivity of the soil. Losing topsoil to erosion contributes to a loss of inherent soil fertility of nitrogen, phosphorus, potassium, and thus to a decline in potential crop yields (Edwin and Muthu, 2020). Loss of productivity results in huge economic loss to the economy. As mentioned above, soil erosion is estimated to cost approximately $44.39 billion to the US economy each year due to the loss of productivity. Moreover, lost farm income due to soil erosion is estimated at $100 million per year.

Soil erosion on farmer fields also represents potential costs to the farmers. Severe soil erosion issues on farmer fields can potentially result in large soil nutrient and fertilizer losses over time. It is estimated that the economic cost to the farmer in lost fertilizer value alone is $1.77 per ton of soil loss (Duffy, 2012). Moreover, there will also be a substantial cost for farmers to repair the erosion problem (i.e., through additional fertilizer application, or additional labor for rehabilitating eroded soils). For example, N fertilizer is commonly used to compensate for the long-term loss of soil fertility through erosion in US agricultural production, and this leads to over a half billion dollars per year in extra fertilizer supply costs to US farmers (Jang et al., 2021).

Soil erosion also produces off-site costs to society, mostly through the degradation in environmental amenities. These costs include clogged roadway ditches, increased turbidity in the water damaging fish (and increasing the need for filtration), lost amenity or recreation values due to lower water quality, and the displaced soil in the water will increase the siltation of water control structures (Duffy, 2012). These costs borne by society as a consequence of soil erosion are known as externalities because they are costs that are not taken into account either by producers or consumers of agricultural goods and services (Inman, 2006). Due to data availability constraints, it is difficult to assess and accurately quantify the main off-site economic costs to the environment induced by soil erosion. However, it has been argued that the off-site costs of erosion are at least an order of magnitude greater than on-site (private) costs to agriculture (Graves et al., 2015; Inman, 2006; Patault et al., 2021).

2.2 Soil Erosion and Agricultural Land Values

Given the private on-site costs of soil erosion to farmers, it is important to empirically examine whether the damage from soil erosion is capitalized into reductions in farmland values. Agricultural land values are generally determined by a complex set of farm and non-farm factors, such as agricultural productivity characteristics and external economic and governmental influences (Dunford et al., 1985; Drescher et al., 2001). However, the principal determinant of agricultural land values is the ability to generate future economic returns. According to relevant agricultural land valuation studies, the common capitalization formula is expressed as the following relationship between current farmland values and expected returns in future periods (Borchers et al., 2014; Ifft et al., 2015; Sant'Anna et al., 2021; Chen et al., 2022a):

$$L_t = \sum_{n=1}^{\infty} \frac{E_t(R_{t+n})}{\prod_{j=1}^{n}(1+r_j)} \tag{1}$$

where L_t is agricultural land values, $E_t(R_{t+n})$ is the expected net economic returns in period $t+n$, and r_j is the discount factor. Traditional studies use rents or economic returns to agricultural production as a measure of expected returns, but a number of studies expand the definition to include potential returns for conversion to higher valued land use activities, such as residential or commercial use (Goodwin et al., 2003) and government payments (Weersink et al., 1999; Ifft et al., 2015; Ciaian et al., 2021), or the net returns from a soil conservation investment (Ervin and Mill, 1985; Chen et al., 2022a). Specifically, along the lines of Hertzler et al. (1985), the land value impacts of erosion can be estimated by defining the present value of net farm returns to include the farmers' cost of erosion (i.e., due to lost productivity and/or the additional soil remediation costs) as follows:

$$PV_t = \sum_{n=1}^{\infty} \frac{E_t(B_{t+n} - C_{t+n})}{\prod_{j=1}^{n}(1 + r_j)}, \tag{2}$$

where PV_t is the present value of the change in net returns from the agricultural land, B_{t+n} is the inherent static returns from agricultural production (that embodies the soils' inherent productivity), and C_{t+n} is total user costs that measure the value of decreases in static returns over time because of crop yield productivity declines and increasing operating costs. Therefore, in the context of the effect of soil erosion on land values, it can be the case that the inherent "natural" flow of the returns from land will be decreased through the additional flow of costs due to lower soil productivity and/or the typically higher operating costs due to erosion. Therefore, soil erosion issues can potentially be a significant component adversely affecting the expected future economic returns of farmland, and consequently influencing the value of farmlands. Despite this key conceptual insight, there has been no recent study that has empirically shown how different levels and types of soil erosion affect farmland values in the US Midwest.

3 Data and Empirical Approach

3.1 Data Sources and Summary Statistics

The data used in this study are collected from a variety of sources. First, the main dependent variable of interest is a measure of agricultural land value ($/acre) at the county-level. We utilize the agricultural land value data set from the USDA-NASS Census of Agriculture (AgCensus) conducted in the following years: 2007, 2012, and 2017. It is the leading source of uniform and comprehensive agricultural data for every state and county in the US. Farmers are asked to estimate the current market value of the surveyed parcel that he or she operates. Then, the market value of land reported in the census of agriculture is measured as of December 31 of the census year. This farmland value survey provides a good indication of the direction of change and level of value, but it is important to note that there are differences between agricultural land estimates based on surveys and those based on actual agricultural land transaction prices. The AgCensus farmland value data are still based on an opinion survey that represents who is being surveyed, and the survey estimates are usually higher than transaction prices (Stinn and Duffy, 2012).

After collecting farmland value data, we then gathered the information for our main independent variables of interest - measures of soil erosion levels. We utilize the county-level data for annual soil loss caused by erosion (in tons/acre) collected from the National Resources Inventory (NRI) program of the USDA Natural Resource Conservation Service (NRCS). The NRI program provides scientifically detailed and credible information on the status, conditions, and trends of land, soil, water, and related resources of the US (Larson et al., 1983; Kertis, 2006; Doetterl et al., 2012). The method used by the NRI program is considered the most extensive quantitative approach performed on the occurrence and amount of soil erosion in the US, and the data set has been utilized in numerous past studies (see, among others, Goodwin and Smith (2003); Cruse et al. (2006); Hernandez et al. (2013); Chen et al. (2022b)).

The NRI soil erosion data is currently conducted using a continuous inventory process — data are gathered for each year's growing season from a scientifically selected subset of "foundation" sample segments established in the 1997 NRI. Then, the NRI applies a stratified two-stage, unequal probability area sampling scheme to establish the sampling units across the nation. The first-stage-sampling unit is an area segment of land, while the second-stage sampling units are points located within the area segments. The national "foundation" or framework sample consists of about 300,000 area segments and 800,000 sample points. Data are then collected from all sampling units by remote sensing (primarily photo interpretation) for both the first- and second-stage, supported by administrative records and on-site field investigation. On-site measurements of soil characteristics for a sub-sample of units are then used to further validate the remote sensing data. Overall, the county-level NRI data set utilized in this study provides detailed information about annual soil loss caused by two major types of erosion for the years 2007, 2012, and 2015: (1) water erosion, which is the removal of soil layers from the land surface by the action of rainfall and runoff; and (2) wind erosion, which includes the process of detachment, transport, and deposition of soil by wind. This soil erosion data we use geographically covers 646 counties in the following twelve US Midwest states: Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, Ohio, Oklahoma, South Dakota, and Wisconsin.

In addition to data on agricultural land values and soil erosion levels, we also utilize weather variables, government payments, and county population data collected from a variety of sources to estimate regressions that represent the spirit of the capitalization formula in Equation (1). First, we collect the weather data from the Parameter-Elevation Regression on Independent Slopes Model (PRISM) climate dataset. PRISM dataset is recognized world-wide as one of the highest-quality spatial climate data sets currently available and is the USDA official climatological data. The relevant weather variables utilized in the study include: the number of growing degree days (8-29°C) and heating degree days (above 29°C), precipitation, and precipitation squared (Schlenker and Roberts, 2009). All degree days and precipitation used in this analysis are accumulated over the growing season months from May to September. Then, county-level government payments and population estimates are obtained from the US Bureau of Economic Analysis (BEA). The government payments variable consists of deficiency payments under price support programs (for specific commodities), disaster payments, conservation payments, and direct payments to farmers under federal appropriations legislation. We include weather, government payments, and population variables as controls in our specification since environmental conditions, government payment, and population level in each county vary over time and can influence agricultural land values.

Brief descriptions of the variables utilized in this study, as well as the corresponding summary statistics, are presented in Table 1. The average agricultural land value from the census of agriculture for the twelve states is \$3932.35 per acre (for the census years 2007 and 2012). The average annual total soil loss due to water erosion for the twelve states is 3.86 tons per acre and the average annual total soil erosion caused by wind is 0.47 tons per acre.

3.2 Empirical Strategy

To determine the impact of soil erosion on agricultural land values, we utilize our main empirical specification defined as follows:

$$L_{it} = \theta S_{it} + \beta \mathbf{X}_{it} + \eta_t + \gamma_i + \varepsilon_{it} \tag{3}$$

where L_{it} denotes agricultural land values (in nominal \$/acre) in county i at time t, S_{it} represents the annual soil loss caused by water erosion, wind erosion, or water and wind erosion combined for county i in year t, η_t are the year fixed effects, γ_i are the county fixed effects, and ε_{it} is the error term.

As mentioned in the previous section, the vector $\mathbf{X}_{it}$ includes the following control variables: weather, government payment, and population level. We include these variables in the specification to control for other observable county- and time- varying factors that can potentially affect agricultural land values, other than soil erosion levels. For the weather variables, we include the number of growing degree days (8-29°C) and heating degree days (above 29°C), precipitation, and precipitation squared. These are the typical variables utilized in the climate change economics literature and account for how climate/weather influences agricultural land values (Ortiz-Bobea, 2020; Chen et al., 2022a). Then, county-level federal government payment levels are also included in the specification because farmlands that receive more direct government payments may have higher returns that are embodied in the capitalization formula (Goodwin et al., 2003). Moreover, we include total population of each county in the specification to control for the effect of human activities or urbanization pressures on agricultural land values. All of these control variables are commonly used to account for farm and non-farm factors that affect agricultural land values in the land value literature (Weersink et al., 1999; Drescher et al., 2001; Borchers et al., 2014; Ifft et al., 2015; Chen et al., 2022a).

We estimate Equation (3) by primarily utilizing the traditional linear panel fixed effects (FE) model. The linear panel FE approach helps us address potential endogeneity due to time-invariant unobservables. The county fixed effects, γ_i, control for all unobservable time-invariant determinants of agricultural land values such as unobserved soil types or topographical characteristics, and unobserved time-invariant average management abilities of farmers, which can also influence the soil erosion levels. In addition, including year fixed effects η_i allows us to better capture the year-to-year, time-varying shocks affecting all counties in the same way (i.e., unexpected nationwide macroeconomic shocks: economic or population growth, inflation, etc.). We also use standard errors clustered by county to account for year-to-year correlations within a county. The following are the parameters to be estimated: θ, β, η and γ. In this study, θ is the main parameter of interest and represents the impact of soil erosion levels on agricultural land values.

3.3 Robustness Checks

To further validate the stability and strength of our results from the linear panel FE model with regard to the impact of soil erosion on agricultural land values, we also conduct a number of robustness checks. First, we examine the effect of soil erosion on agricultural land values using data only for the "I" states: Illinois, Indiana, and Iowa for census years 2007 and 2012. Second, we implement the relative correlation restrictions (RCR) approach to determine whether estimates from this alternative estimation method are still consistent with our results from the traditional linear panel FE models. Recently developed by Krauth (2016), the RCR approach aims to bound the estimated causal effect of a single endogenous regressor, in the absence of IVs satisfying traditional exclusion restrictions. In our empirical context, the RCR method provides bounds on the effect of soil erosion levels on agricultural land values depending on an assumed range of "deviations from exogeneity". Specifically, the "deviations from exogeneity" in the RCR approach are defined based on a lambda (λ) parameter that describes (a) the unobserved correlation between the variable of interest (S_{it}) and the error term (ε_{it}), relative to (b) the observed correlation between the variable of interest (S_{it}) and the control variables $\mathbf{X}_{it}$. More formally, given equation (3), we make assumptions on λ based on the following equation:

$$corr(S_{it}, \varepsilon_{it}) = \lambda \, corr(S_{it}, \beta \mathbf{X}_{it} + \eta t + \gamma_i), \tag{4}$$

where $\lambda \in [\lambda_L, \lambda_H]$. If $\lambda = 0$, then this corresponds to our linear FE model (with no residual endogeneity assumed). On the other hand, if $\lambda = 1$, then the correlation between soil erosion level and unobservables is the same as the correlation between no-till and the controls.

Krauth (2016) suggests that $[\lambda_L, \lambda_H] = [0, 1]$ is a reasonable benchmark to examine the sensitivity of the linear FE estimates. Hence, if for a reasonable range of λ between zero and λ_H the estimated bounds of the effect of soil erosion level on agricultural land values are still the same sign as the linear FE model (and the bounds are statistically significant), then it requires a larger amount of residual endogeneity (i.e., true $\lambda > \lambda_H$) to invalidate our linear FE results. We can then interpret this as saying that our results are strong (and robust) since small departures from exogeneity do not change inferences from the linear FE model.

4 Empirical Results

Table 2 presents estimates of the effects of water-caused, wind-caused, and the sum of both water- and wind-caused soil erosion on agricultural land values using the linear panel FE estimation approach. In general, we find a negative and statistically significant impact of soil erosion on county-level agricultural land values. Our parameter estimates generally suggest that counties with higher levels of soil erosion tend to have statistically lower agricultural land values, and this marginal land value effect of soil erosion is not explained by climate, government payments, or urbanization pressures. Specifically, our empirical results show that a 1% increase in tons of soil loss per acre due to water erosion can lead to a statistically significant decrease of $235.87 per acre in agricultural land values (at the 1% level of significance). However, we did not find a statistically significant effect of wind-caused soil erosion on agricultural land values (although the direction of the effect is still negative). Lastly, taking the impact of both county-level water and wind soil erosion into account, our estimates show that a 1% increase in the combined water- and wind-caused erosion can statistically decrease agricultural land values by $216.38 per acre (at the 1% level of significance).

It is important to note that our findings indicate that the land value effect of water-caused erosion is statistically significant, while the effect of wind-caused erosion is statistically insignificant. This means that soil loss due to excess moisture or heavy rainfall is more harmful in terms of reducing agricultural land values. Given that water-caused soil erosion is generally considered the most serious cause of soil degradation globally and is also the more dominant soil erosion problem in the US (Lal et al., 1994; Gruver, 2013), our study shows that water erosion in farmer fields could also decrease land values more severely than wind erosion. Nonetheless, the estimated negative effect of wind-caused erosion (although not significant) suggests that soil loss due to strong winds also has the potential to lead to lower agricultural land values.

Our results indicate that the economic damages due to soil erosion are likely capitalized into lower farmland values. An increase in soil erosion can result in a statistically significant decrease in agricultural land values as expected future economic returns from the farmland decrease. Our results are consistent with relevant studies that have generally discussed the relationship between soil health (or soil conservation investment) and farmland values (Ervin and Mill, 1985; Hertzler et al., 1985; Chen et al., 2022a). According to these agricultural land valuation studies, soil erosion could negatively affect expected future economic returns due to productivity loss and higher operating costs of farmers, which in turn influence farmland values. Our study therefore provides further empirical evidence of the negative relationship between major types of soil erosion and agricultural land values in the US.

To better interpret and understand the magnitude of the estimated effect of soil erosion on agricultural land values, we conduct the following back-of-the-envelope calculation. Based on the summary statistics of the 2007 and 2012 NRI surveys, the annual average soil loss caused by water erosion is about 3.86 tons per acre and the average soil loss due to wind erosion is about 0.47 tons per acre in the US. Considering the US total acres of cropland in the US (around 396 million acres, according to the USDA-NASS), this translates to annual US soil erosion levels of approximately 1.53 billion tons of soil loss due to water erosion, and 186.12 million tons of soil loss due to wind erosion (i.e., with a total of 1.72 billion tons of soil loss annually caused by both erosion types). Therefore, based on the total cropland acres in the US, our estimates indicate that a 1% increase in water erosion level (i.e., 15.3 million tons of soil loss) can potentially cause a yearly total economic loss (in terms of land value reduction) by about \$93.40 billion (396 million acres $\times$ \$235.87/acre). This is a fairly substantial estimate of economic damage due to soil erosion when compared with the estimated economic impact of soil erosion on the US economy based solely on loss of productivity (approximately \$44.39 billion based on previous studies, as mentioned above). Therefore, our results suggest that there are substantial costs to farmland owners caused by a decrease in their asset value to due soil erosion, and also confirm the importance of capturing the soil erosion impact in land value capitalization studies.

With regards to the control variables in the empirical specification, the parameter estimates from our linear panel FE models largely follow expectations. For example, the estimation results show that an increased incidence of more extreme heating degree days (higher HDD) in the cropping season tends to decrease agricultural land values. We also find that county-level population has a positive effect on agricultural land values, which is consistent with the notion that the impact of urbanization pressure and potential development opportunities are associated with high farmland values (Ifft et al., 2015).

The robustness check results are presented in Tables 3-4. All the robustness check results are consistent with findings from our main empirical specification in Table 2. For example, in Table 3, we show results of the first robustness check where we limit the analysis to just the "I" states. The parameter estimates associated with the soil erosion level variable are negative and significant in these runs, though the magnitude of the impact of water erosion and the sum of both water and wind erosion is relatively lower than the estimates from our main specification.

For our second robustness check, we utilize an alternative estimation strategy— the RCR estimation approach. Table 5 presents the estimates bounds of the impact of water-caused, wind-caused, and both water- and wind-caused erosion on agricultural land values. The RCR results suggest that our linear FE model specification results are strong and robust to large departures from exogeneity.[1] In other words, if the correlation between soil erosion levels and the unobservables is no larger than the correlation between soil erosion level and the observables in the model specification (i.e., $\lambda = 1$), then the RCR bounds of the estimated soil erosion impacts are still significantly negative with fairly narrow bounds. This means that it will take a large amount of endogeneity due to county-time-varying unobservables (e.g., very high correlation) to overturn our results. Hence, the inclusion of county fixed effects are likely sufficient to control for endogeneity concerns in our empirical context.

5 Conclusion

The value of agricultural land is generally determined by the productive capacity of the soil and its ability to generate future economic returns to agricultural production (Borchers et al., 2014; Chen et al., 2022a). Degradation in soil fertility through erosion can have a

[1] Krauth (2016) indicates that moderate departures from exogeneity is when the lambda parameter is around 0.5, and large departures is when it is around 1.0 or larger.

significant impact on the ability of soil to perform its main productivity-enhancing functions and potentially decrease agricultural land values. However, empirical studies addressing the direct impact of soil erosion levels on farmland values have been very limited. Based on a novel panel data set with detailed information on county-level soil erosion levels and agricultural land values, we utilize the linear panel FE models for a variety of empirical specifications and alternative estimation procedures to analyze the effects of two major types of soil erosion, water-caused and wind-caused erosion, on agricultural land values in the US Midwest.

Our empirical results suggest a negative and statistically significant impact of soil erosion on agricultural land values in a major US crop production region. For example, our parameter estimates indicate that a 1% increase in the total soil loss caused by both water and wind erosion can lead to a decrease in agricultural land values by $216.38 per acre. We believe that the magnitude of this estimated farmland value reducing effect from soil erosion is not trivial (and is actually relatively substantial). Therefore, our study provides new empirical evidence that both the on-site and off-site economic and environmental damage of soil erosion are likely to capitalized into farmland values.

Findings from our study point to several important implications. First, our empirical results indicate that soil erosion can cause fairly substantial amount of economic damage that can be captured through reduction in agricultural land values. Therefore, the estimated economic damage from our study provides further justification for government subsidies in light of the argument that "off-site" (mostly environmental) economic damages from soil erosion is at least as large as private "on-site" damages of soil erosion. Government support for cost-share programs like the Environmental Quality Incentives Program (EQIP), which helps encourage adoption of soil erosion control practices (e.g., no-till and cover crops), will likely play an important role to mitigate the economic damage from soil erosion (Chen et al., 2022b). Second, given the significant negative farmland value capitalization effect of soil erosion and the associated potential dollar value loss, demonstrating this farmland value impact and communicating this additional economic cost to farmland owners can also help further encourage soil erosion control strategies. Knowing that erosion can reduce the asset value of their land, farmland owners renting out their land have incentives to encourage their tenants to implement soil erosion control strategies.

Even though our study provides a couple of important insights about the impact of soil erosion on agricultural land values, it is important to acknowledge a number of limitations of this study and discuss potentially fruitful directions for future research. First, even though the geographical scope of the current study is fairly wide relative to earlier studies, it is still limited only to the US Midwest. To enhance external validity and explore heterogeneity effects, it may be necessary to investigate the impact of soil erosion levels on farmland values for other regions in the US. Examining soil erosion impacts in largely irrigated versus non-irrigated regions of the country would be useful. Second, we have only investigated empirical specifications with a small set of control variables. It is important to conduct further robustness checks using a number of different sets of control variables. Third, interaction effects of soil erosion and climate variables were not examined in this manuscript. Further exploration of whether (and how) soil erosion can further exacerbate extreme weather events would be an interesting avenue for future research. Last, our empirical analysis dealt with the issue of endogeneity due to time-county-varying unobservables by implementing a recently developed external-IV free model of Krauth (2016). It would be useful to evaluate whether our inference would still hold using traditional panel IV methods if valid external instruments are available, and also through the use of other "external-IV-free" econometric approaches. We leave all these potential research directions for our future work.

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Table 1: Description and Summary Statistics of Variables

Variable	Description	Mean	St. Dev.	Min.	Max.
Agland_value	Agricultural land values in Census data ($/acre)	3932.35	1688.76	701	10471
water_erosion_level	Annual soil loss due to water erosion (tons/acre)	3.86	2.45	0.13	15.32
wind_erosion_level	Annual soil loss due to wind erosion (tons/acre)	0.47	1.23	0	11.55
water_wind_erosion_level	Annual soil loss due to water and wind erosion (tons/acre)	4.33	2.35	0.65	15.32
GDD	Growing degree days ($8-29$°C)	2069.33	232.06	1395.98	2709
HDD	Heating degree days (above 29°C)	6.77	11.46	0	85.09
prep	Precipitation (growing season average, 1000mm)	428.52	138.25	151.46	998.82
prep_s	Precipitation squared	202731.60	136610.60	22940.98	997649.20
population	County-level population	75432.66	255158.30	797	5285107
government_payment	Federal government payments ('000 $)	5291.33	3166.49	41	22843

Table 2: Estimates of the Effects of Soil Erosion Level on Land Values

	(1)	(2)	(3)
Water erosion level	-235.8686***		
	(38.4964)		
Wind erosion level		-5.8480	
		(171.4187)	
Water and wind erosion level			-216.3842***
			(37.1580)
GDD	-6.9052***	-6.4594***	-6.8988***
	(0.9127)	(0.9343)	(0.9159)
HDD	-32.2334***	-38.1254***	-32.9400***
	(2.8838)	(3.0586)	(2.8864)
Precipitation	-6.0476***	-5.5832***	-5.7862***
	(0.9767)	(1.0183)	(0.9985)
Precipitation squared	0.0039***	0.0034***	0.0036***
	(0.0010)	(0.0010)	(0.0010)
Population	0.0114***	0.0118***	0.0116***
	(0.0027)	(0.0028)	(0.0028)
Government payment	-0.0742	-0.0718	-0.0709
	(0.0389)	(0.0397)	(0.0386)
County FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Adjusted R^2	0.787	0.773	0.786
Observations	1291	1291	1291

Note: This table presents the results of the second robustness check (including year fixed effects in the specification instead of linear time trend). Each specification includes county fixed effects. The Standard errors are clustered by county. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3: Robustness Check: Estimates of the Effects of Soil Erosion on Land Values in "I" states

	(1)	(2)	(3)
Water erosion level	-180.4934***		
	(43.5647)		
Wind Erosion level		-1438.0072	
		(912.9014)	
Water and wind erosion level			-188.0797***
			(43.7896)
GDD	-0.8774	-1.4084	-0.9087
	(1.9849)	(1.9600)	(1.9837)
HDD	-20.2604*	-36.7779***	-19.3512
	(10.1037)	(8.3227)	(10.0577)
Precipitation	-6.3383	-6.7351*	-6.2862
	(3.2603)	(3.0983)	(3.2550)
Precipitation squared	0.0040	0.0046	0.0039
	(0.0035)	(0.0033)	(0.0035)
Population	0.0297	0.0300*	0.0298
	(0.0154)	(0.0147)	(0.0154)
Government Payment	-0.1281*	-0.1077	-0.1281*
	(0.0617)	(0.0600)	(0.0617)
Time Trend	429.2303***	448.8847***	427.1595***
	(27.0581)	(25.9278)	(26.9594)
County FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Adjusted R^2	0.862	0.858	0.862
Observations	586	586	586

Note: This table presents the results of the first robustness check (using agricultural land values and soil erosion levels only for the "I" states: Illinois, Indiana, and Iowa). Each specification includes county fixed effects. The Standard errors are clustered by county. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 4: Robustness Check: Relative Correlation Restriction (RCR) estimation strategy

Soil erosion measure	Water erosion	Wind erosion	Water and wind erosion
Dependent variable:	Agricultural land value	Agricultural land value	Agricultural land value
Linear FE model estimate	-235.8686***	-5.8480	-216.3842***
(95% CI)	(-307.6204, -164.1168)	(-276.0877, 264.3918)	(-285.2240, -147.5443)
Bounds, $0 \leq \lambda \leq 0.1$	[-256.3815, -235.8686]***	[0.8994, -5.8480]	[-234.6300, -216.3842]***
(95%CI)	(-311.6218, -182.7026)	(-242.6000, 251.8660)	(-287.9774, -165.0664)
Bounds, $0 \leq \lambda \leq 0.2$	[-277.1349, -235.8686]***	[7.6663, -5.8480]	[-253.0648, -216.3842]***
(95%CI)	(-334.7532, -182.7026)	(-242.6000, 273.8976)	(-308.7233, -165.0664)
Bounds, $0 \leq \lambda \leq 0.3$	[-298.1637, -235.8686]***	[14.4530, -5.8480]	[-271.7150, -216.3842]***
(95%CI)	(-358.4550, -182.7026)	(-242.6000, 296.8473)	(-329.9551, -165.0664)
Bounds, $0 \leq \lambda \leq 0.4$	[-319.5057, -235.8686]***	[21.2597, -5.8480]	[-290.6088, -216.3842]***
(95%CI)	(-382.7615, -182.7026)	(-242.6000, 320.5887)	(-351.6945, -165.0664)
Bounds, $0 \leq \lambda \leq 0.5$	[-341.2028, -235.8686]***	[28.0865, -5.8480]	[-309.7773, -216.3842]***
(95% CI)	(-407.7169, -182.7026)	(-242.6000, 345.0143)	(-373.9708, -165.0664)
Bounds, $0 \leq \lambda \leq 1$	[-456.8102, -235.8686]***	[62.5278, -5.8480]	[-411.0379, -216.3842]***
(95%CI)	(-544.5975, -182.7026)	(-242.6000, 474.8201)	(-495.0523, -165.0664)

Note: This table presents the linear FE model estimates and RCR bounds for the effect of soil erosion on agricultural land values.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$