Journal of Environmental Economics and Management 68 (2014) 507–526

Contents lists available at ScienceDirect

Journal of Environmental Economics and Management

journal homepage: www.elsevier.com/locate/jeem

The environmental effects of crop price increases: Nitrogen losses in the U.S. Corn Belt

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ARTICLE INFO

Article history:
Received 10 June 2013
Available online 13 October 2014

JEL classification:
Q15
Q53

Keywords:
Crop rotation
Spatial
Water quality
Dynamic panel

ABSTRACT

High corn prices cause farmers to plant more corn on fields that were planted to corn in the previous year, rather than alternating between corn and soybeans. Cultivating corn after corn requires greater nitrogen fertilizer and some of this nitrogen flows into waterways and causes environmental damage. We estimate the effect of crop prices on nitrogen losses for most fields in Iowa, Illinois, and Indiana using crop data from satellite imagery. Spatial variation in these high-resolution estimates highlights the fact that the environmental effects of agriculture depend not only on what is grown, but also on where and in what sequence it is grown. Our results suggest that the change in corn and soybean prices due to a billion gallons of ethanol production expands the size of the hypoxic zone in the Gulf of Mexico by roughly 30 square miles on average, although there is considerable uncertainty in this estimate.

Introduction

Agricultural production generates externalities through its effects on environmental goods such as water quality, wildlife habitat, and carbon sequestration. As crop prices change, farmers change their planted acreage, which in turn changes the generation of these externalities. For example, it has been argued that higher crop prices due to the production of ethanol have increased nutrient losses from the Corn Belt into surface water (e.g., Donner and Kucharik, 2008; Secchi et al., 2011; Langpap and Wu, 2011), increased monoculture production systems that are associated with losses of biocontrol services (Landis et al., 2008), and increased greenhouse gases due to agricultural land use expansion (e.g., Searchinger et al., 2008).

In this paper, we estimate the marginal response of nitrogen losses to changes in crops prices for almost all cultivated fields in Iowa, Illinois, and Indiana. Nutrient losses from crop production in this region are cited as a leading cause of the "dead zone" in the Gulf of Mexico (Dale et al., 2010). The Economist (2012) calls the dead zone an "ecological disaster" that results in losses to fisheries valued at roughly $2.8 billion per year, among other damages. Rabotyagov et al. (2014) provide an overview of the impact of hypoxic conditions on ecosystem services and note that dead zones are an increasing concern in many regions of the world. Local water quality is also a serious concern within this region due to nutrient losses. For

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http://dx.doi.org/10.1016/j.jeem.2014.09.002
0095-0696/

example, the Illinois EPA (2012) lists several impaired waters and cites crop production as one of the leading sources of these impairments. Several studies have shown that high nutrient concentrations in local water bodies are directly related to row crop production (Schilling and Libra, 2000; Arbuckle and Downing, 2001).

Marginal nitrogen losses from changes in crop prices depend on land use response to prices and the effect of land use changes on nitrogen losses. We estimate the land use response to prices using the econometric model from Hendricks et al. (2014b). We then integrate these estimates with the Soil and Water Assessment Tool (SWAT) to simulate the ensuing effects on nitrogen losses.[1]

For the main explanatory variables in our econometric model, we use futures prices measured during a pre-harvest period on contracts for post-harvest delivery. We adjust for spatial variation and government payments, so our price variables proxy for the farmer's output price expectations at planting time. We assume that these expected price variables are exogenous to planted crop acreage. The dominant sources of variation in these prices are the recent increase due to strong global demand and U.S. ethanol production (Carter et al., 2013) and prior-year yield shocks (Roberts and Schlenker, 2013). These two sources of variation represent shocks to the demand for current-year supply, so they can be used to identify the acreage response. Nonetheless, our exogeneity assumption would fail if planted acreage were affected by anticipated yield shocks and if futures prices were to respond to the anticipated change in planted acreage. Supporting exogeneity, Hendricks et al. (2014a) find only a small bias in regressions with acreage as the dependent variable rather than production. We assess the robustness of our results to our exogeneity assumption by including the realized yield shock as a control to proxy for anticipated yield shocks.

We estimate the marginal nitrogen losses at a high spatial resolution. Our estimates account for spatial variation in crop rotations, land-use response, and water-quality impacts, so they reveal how the environmental effects of agriculture depend not only on what is grown, but especially on where and in what rotation it is grown. We also report the aggregate marginal losses as nitrogen loss elasticities with respect to changes in crop prices. These elasticity estimates are important for understanding the effect of government policies on nitrogen losses from the Corn Belt. For example, we use these elasticities to estimate the effect of ethanol production in the United States on the size of the hypoxic zone in the Gulf of Mexico. Our elasticity estimates are also important inputs for estimating the effect of U.S. farm subsidy programs on nitrogen losses. Our research is related to Muller and Mendelsohn (2007) who estimate the aggregate marginal damages and the spatial heterogeneity of marginal damages from air pollution. Our work is also related to Antle et al. (2003) who use an integrated assessment model to estimate the supply of sequestered carbon from agriculture accounting for the spatial heterogeneity of crop rotations, production practices, and soil carbon rates.

Accurately estimating the environmental damages associated with crop price changes requires a model that incorporates production dynamics. Crop rotations—alternating crops between years for a given field—are common because planting a crop on the same field in consecutive years decreases crop productivity, increases pest populations, and raises costs. It is common for farmers in the Corn Belt to rotate between corn and soybeans. Planting corn after soybeans increases corn yields (holding inputs constant) and reduces the optimal fertilizer application because nitrogen carries over from soybeans the previous year.[2] The dynamics of crop rotations have important water quality implications because corn planted after corn leads to greater nitrogen losses than corn planted after soybeans—likely due to the fact that more fertilizer is applied to corn after corn.

We account for the dynamics in our econometric model by specifying the year-to-year transitions between growing corn and soybeans as a first order Markov process. We use the resulting Markov transition probabilities to calculate the probability of a corn-after-corn sequence, a corn–soybean rotation, and a soybeans-after-soybeans sequence—as well as the short-run (1 year) and long-run (5–10 years) marginal effects of price changes on these sequences. We find that, in response to a price shock, changes in nitrogen losses are smaller in the short run than in the long run. This result arises because nitrogen losses are largest from fields with consecutive years of corn, and corn-after-corn acreage responds to a price shock *less* in the short run than in the long run. For example, if the price of corn increases permanently, some land switches from a corn–soybean rotation to continuous corn. Roughly half of this land was planted to corn in the previous year, so it experiences relatively high nitrogen losses beginning in the first year. However, the other half of this land was planted to soybeans in the previous year, which mitigates the nitrogen losses from planting corn in the first year. These dynamics stand in contrast to the dynamics of aggregate corn acreage. Using the same model, Hendricks et al. (2014b) show that aggregate corn acreage responds to price shocks *more* in the short run than in the long run. We explain in the first section how these seemingly contradictory results are consistent with each other.

Accurately estimating the environmental damages associated with crop price changes also requires a model that incorporates spatial heterogeneity. There are two reasons to model spatial heterogeneity in our context: (i) the spatial distribution of the nitrogen losses is inherently important, and (ii) estimates of aggregate nitrogen losses may be biased if they ignore spatial heterogeneity. Spatially explicit estimates of marginal nitrogen losses are useful for assessing the effects of crop price changes on regional water quality. Furthermore, heterogeneous incentives to rotate crops and heterogeneous

[1] The SWAT model has been widely used to assess the impacts of landcover and management practices on water and nutrients at the field and watershed scale (Gassman et al., 2007; Douglas-Mankin et al., 2010; Tuppad et al., 2011).

[2] Soybeans are a nitrogen-fixing crop.