The Effect of Payments per acres for Ecosystem Services on CRP Land Enrollment: A Nonlinear Regime-Switching Approach

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The results are preliminary, please do not cite

Selected Paper prepared for presentation at the 2022 Agricultural & Applied Economics Association Annual Meeting, Anaheim, CA; July 31-August 2

ABSTRACT

Regime shifts in conservation programs occur due to abrupt changes that produce an unanticipated response. Analyzing such shifts is complicated by nonlinear dynamics. Here, we explore how the ecosystem service payments per acre for land retirement through the Conservation Reserve Program (also called the rental rate) affect program acreage under different crop price regimes using a nonlinear model. We use county-level data from 1986 to 2019 and adopt a land-use framework estimated with Panel Smoothing Transition Regression for the United States. We find that ecosystem service payments per acre have nonlinear effects on land enrollment, as the effect of increasing CRP rental rate on CRP acreage is higher under low crop prices but declines under high crop price regimes. Moreover, we confirm a nonlinear relationship between payments per acres elasticities and the transition variable–measured by the transformed crop price index–and reveal that the sensitivity of payments per acre elasticities occurs in the low range of the transition variable when the crop price is low.

INTRODUCTION

The Conservation Reserve Program (CRP) is a land retirement program that operates with a dual-goal structure where agricultural lands are restricted for conservation purposes in exchange for ecosystem service payments (Wu & Lin, 2005). The program encourages farmers to voluntarily enroll their highly erodible lands (HEL) for conservation purposes and, at the same time, gain monetary benefits. Nonetheless, empirical evidence suggests that farmers abandon conservation practices for continuous cropping on HEL when crop prices rise (USDA FSA, 2018; Langpap and Wu, 2011). A recent study by Holland et al. (2020) reports increases in non-compliance and continuous agricultural production on HEL in the US Corn Belt region when crop prices are high.

We evaluate how fluctuations in agricultural commodity prices influence conservation programs by addressing the following objectives. First, we establish the causal relationship between the payments offered to the farmers and CRP acreage under different crop price regimes. Second, we verify the existence of regime switches in the CRP program to establish the presence of nonlinear associations. This study is essential as the CRP acreage and rental payments have undergone several changes after its inception. For instance, ecosystem service payments per acre offered to farmers have been reduced by 85% and 90% for both general and continuous sign-ups, respectively, while the enrollment cap is expected to increase from 24 million to 27 million acres by 2023 (USDA, 2020). Crop prices have increased, farm exports are at a record high, and the U.S. Department of Agriculture (USDA) projects an additional 2.1 million acres of cultivation of major field crops under these circumstances (USDA, 2020).

We use a flexible estimation technique that does not restrict the functional form of the data generating process and accounts for both linear and nonlinear effects in the conservation program. We adopt a panel smoothing transition model (PSTR) to determine the effect of the CRP payment rate per acre (or rental rate) on CRP acreage under different crop price situations. This method exploits the regime switches between the CRP rental rate and the CRP acreage by identifying transitions in the conservation program. From our results, we find that a 10% increase in payment per acre is associated with a 2.9% increase in CRP acreage when the crop price is low, but a 2.5% increase in CRP acreage when the crop price index is high. Furthermore, we indicate that it would cost the government approximately $25 million more to add 10 million acres under high crop prices than it would under low crops, irrespective of the enrollment cap. Subsequently, we show that the relationship between CRP rental rate elasticity and standardized crop price is nonlinear and has an L-shaped form. This relationship is anticipated as the payment elasticity decrease with an increase in the crop price index and remain constant with further increase in the crop price index.

EMPIRICAL APPROACH

We use a land rent maximization as the theoretical framework for our study. We assume that a landowner allocates a parcel of land to a particular use that provides the highest net returns based on a stream of different land uses. We specify a reduced-form log-log land use framework equation as:

$$lnCRP_{i,t} = \sum_{j=1}^{L} \varphi_j lnCRP_{i,t-j} + \beta_1 lnR_{i,t} + \boldsymbol{\beta_k lnX_{i,t}} + \mu_i + \varepsilon_{i,t} \qquad (1)$$

where the outcome variable, $CRP_{i,t}$ denotes the CRP acreage in county *i* at time *t*; j stands for the j-year lagged; L is the maximum lag of the dependent variable; $R_{i,t}$ is the ecosystem service payment per acre in county *i* at time *t*; $\boldsymbol{X_{i,t}}$ is a vector of control variables that affect the CRP acreage including Crop price, $CP_{i,t}$ in county *i* at time *t*; μ_i is the county specific effects that capture geographical characteristics and time-invariant factors that affect the CRP acreage; and $\varepsilon_{i,t}$ is the error term. We include a lagged dependent variable as an independent variable in our model to account for acreage in existing CRP contracts at time *t*. The vector $\boldsymbol{X_{i,t}}$ includes population density in county *i* at time *t*, real net farm earnings in county *i* at time *t*, real median household income in county *i* at time *t*, annual average temperature in county *i* at time *t*, and the Laspeyres crop price index for eight major row crops in the United States in county *i* at time *t*.

We adopt the Hausman (1996) endogeneity correction technique to resolve the simultaneity and the selection bias between the CRP acreage and the CRP rental payment as noted in the CRP literature (Miao et al., 2016; Jang & Du, 2018). The CRP rental payment endogeneity equation is specified as: $R_{j,i,t} = \alpha_0 + \alpha_j \omega_{j,t} + \mu_{j,i,t}$; where $R_{j,i,t}$ is the rental payment *j* in county *i* at time *t*. The determinant of rental payment in county *j* are $\omega_{j,t}$, the other counties rental payments that are assumed not to have any county–specific time shifting effect; $\mu_{i,t}$ is the stochastic term. The identifying assumption is that the error term in the endogeneity equation are independent across counties. Thus, we use fixed effects to eliminate the county specific components and derive a state proxy variable (excluding the county being instrumented) to eliminate the endogeneity. Similarly, we control for the endogeneity of crop prices on CRP acreage by following Miao et al., (2016) and Bellemare (2015) by using temperature together with month and year dummies as instrumental variables. We include the dummies to control for seasonal variations and eliminate the predictability of natural disasters (Bellemare, 2015). In addition, we use the control function technique that uses a two–stage residual inclusion (2SRI) strategy to mitigate the endogeneity problem (Wooldridge, 2015).

To add a nonlinear, nonmonotonic structure to the CRP enrollment equation that accounts for farmers' behavioral shifts under different crop price regimes, we follow Gonzalez et al. (2018) by incorporating a PSTR model into the log-log land use framework as follows:

$$lnCRP_{i,t} = \sum_{j=1}^{L} \varphi_j lnCRP_{i,t-j} + \mu_i + \beta_1 lnR_{i,t} + \beta_2 lnR_{i,t} g(\phi_t; \gamma, c) + \boldsymbol{\beta_k lnX_{i,t}} + \boldsymbol{\pi \hat{v}'_{i,t}} + \varepsilon_{i,t} \qquad (2)$$

$$\text{where } g(\phi_{i,t}; \gamma, c) = \left(\frac{1}{1+exp\,[\gamma \prod_1^m (\phi_{i,t} - C)]}\right), \gamma > 0$$

$g(\phi_{i,t}; \gamma, c)$ is a smooth, continuous, logistic continuum of observations between two extreme regimes that are bounded between 0 and 1; $\phi_{i,t}$ is the crop price transition variable; γ is the speed-of-adjustment that determines how quickly the model regimes shift; c is the threshold parameter that defines the point at which farmers are likely to restrict land for conservation use and defy conservation practices under the transition variable; and $\hat{v}'_{i,t}$ is the vector of the residual values from the first stage regressions. In the instance where γ approaches infinity, the transition between the extreme regimes is sharp, and the PSTR attains a panel threshold model (Hansen, 1999). On the contrary, if γ approaches zero, the transition function $g(\phi_{i,t}; \gamma, c)$ is constant, and the model assumes a standard linear with county-specific fixed effects. β_1 and $(\beta_1 + \beta_2)$ are payment per acre effects in two extreme regimes. Regime one represents the period with the lowest crop prices, whereas regime two represents the period with the highest crop prices. Most farms make enrollment decisions with some state in between the two extremes, with an infinite number of such regimes lying on that continuum and their location on the continuum expressed by the value of g. As part of the study, we derive the regime-switching intervals by computing the ecosystem service payments per acres elasticity as:

$$\text{Payments per acres elasticity} = \frac{\partial CRP_{i,t}}{CRP_{i,t}} \Big/ \frac{\partial R_{i,t}}{R_{i,t}} = \frac{\partial \ln (CRP_{i,t})}{\partial \ln (R_{i,t})} = \beta_1 + \beta_2(\phi_t^*; \gamma, c) \qquad (3)$$

If the switch phenomenon exists, then we expect the payments per acres elasticity to change over time as the crop prices index embodied in the transition variable ϕ_t^* change. In addition, we determine the points at which these regime–switches occur by computing the elasticity of payments per acres elasticity (EPE) change with respect to the transition variable based on our transition function:

$$EPE = \frac{\partial(\widehat{\beta_1}+\widehat{\beta_2}g(\phi_t^*;\gamma,c)}{\partial(\widehat{\beta_1}+\widehat{\beta_2}(\phi_t^*;\hat{\gamma},\hat{c})} / \frac{\partial\phi_t^*}{\phi_t^*} = \frac{\widehat{\beta_2}*\hat{\gamma}*e^{-\hat{\gamma}(\phi_t^*-\hat{c})}}{(e^{-\hat{\gamma}(\phi_t^*-\hat{c})}+1)^2} * \frac{\phi_{it}^*}{(\widehat{\beta_1}+\widehat{\beta_2}(\phi_t^*;\hat{\gamma},\hat{c})} \quad (4)$$

Following Gonzalez et al. (2018), a three-step strategy is used to estimate and validate the PSTR model. First, a linearity test is conducted to determine the appropriate order of the transition function. This involves a homogeneity test that is conducted to verify the regime-switch hypothesis under varying crop price conditions. Second, an estimation process consists of a two-step procedure where the panel data is demeaned, and a nonlinear least square (NLS) method is used to estimate the PSTR model. Third, a misspecification test is conducted to establish that there is no remaining nonlinearity in the model.

DATA CONSTRUCTION AND SUMMARY STATISTICS

The model estimates are based on county-level data from 877 counties in the Lake States, Corn-belt States, Delta States, Southern States, and The Plains States from 1986–2019. Data on CRP acreage and the CRP rental rate offered to farmers are obtained from the USDA–Farm Service Agency (FSA). The CRP acreage denotes the total acres of land enrolled in the CRP in each county. The CRP rental rate is the per-acre payment offered to farmers for enrolling their land into the program and differs by county. Economic and demographic factors are critical determinants of land use pattern, so we control for population density and median household income per capita in the model. Population density is expressed as $PD_{it} = (Pop_{it}/LA_{it})$; where PD_{it} is the population density in county i at time t, Pop_{it} is the number of people in county i at time t, and LA_{it} is the total land area in county i at time t. Data on population and land area are obtained from the Bureau of Economic Analysis (BEA) and the United States Department of Agriculture (USDA) respectively. Data on median household income data is obtained from the BEA. In addition, we control for farming earnings in the model as earnings from agriculture can influence farmers' enrollment decisions. This comprises the net farm income and cost arising directly from the current production of agricultural commodities either from livestock or crops within a county at a specific time. Income and price variables are deflated to account for inflation. We control for crop prices, a measure of the row-crop market strength, as studies show that agricultural prices tend to influence CRP enrollment decisions. We use county-level crop production and deflated state-level prices to construct the Laspeyres crop price index for eight major agricultural commodities using 1986 as the base year (Li et al., 2019). In year $t \in \{1986, \ldots, 2019\}$, the price index is defined as $P_{it}^{a} = (\sum_{l=1}^{8} Pl_{it} Q_{li1986}) / (\sum_{l=1}^{8} Pl_{i1986} Q_{li1986})$, where Pl_{it} is the received price of crop l in state i at time t; and Q_{li1986} is the production of crop l in state i at the base year, 1986. Crop production and price data are obtained from National Agricultural Statistics Service (NASS). We use temperature as a weather variable to capture landowner's expectation of climate conditions. Data for the county-level average temperature were obtained from the Parameter–Elevation Relationships on Independent Slopes Model (PRISM) managed by the Oregon State University. Following Li et al. (2020), the transition variable is transformed and standardized as $\phi_t^{*} = (\phi_t - M_{\phi} / \sigma_{\phi})$, where M_T is the minimum value of ϕ_t, and σ_T is the standard deviation of ϕ_t. We rescale the crop price to have mean 0 and variance 1 to bring the crop price features to a common scale without distorting the differences in the range of the values. Table 1 lists the variables employed and their respective summary statistics.

RESULTS AND DISCUSSION

The homogeneity and sequence of homogeneity tests results are reported in Tables 2 and 3. From the tests conducted, we reject linearity and conclude that the data generating process satisfies the homogeneity conditions and also a regime-switch effect exists.

The smooth transition parameter shows that the transition function estimate is smooth and is a continuum of observations between the two regimes. Based on the PSTR results, a 1% increase in the CRP rental rate increases CRP acreage by 0.29% in the first regime when low crop prices. However, in the second regime when crop prices are high, the impact of the per acre rental payments per acres on CRP acreage declines to 0.248%. The difference in the estimates under the two regimes denotes farmers behavior under varying crop price situations. We illustrate the regime–switching in the CRP rental rate under different crop price situations in Figure 2 and show that it is time-variant and exhibit time–varying heterogeneity. We find that the estimated elasticity increases from 0.274 to 0.287 as the crop price index decreased from 130 in 1995 to 79 in 2002 (Fig. 1). We determine the nonlinear association between the payment per acre elasticity estimates and the crop prices by identifying the thresholds where farmers switch lands from conservation use for cropland use. We confirm that the relationship between the ecosystem service payment per acre elasticity and the crop price index is nonlinear; more succinctly, the elasticities of the ecosystem service payment per acre elasticity to the crop price index is L-shaped in nature (Fig. 2).

CONCLUSION

We adopt a land use framework and integrate with a regime-switching model to investigate the how ecosystem service payment per acre offered to farmer affect CRP acreage under different crop price situations using county-level data from 1986 to 2019. Assessing the consequences of how fluctuating crop price contribute to the varying effect of ecosystem service payment per acres on CRP acreage is challenging, so we adopt the panel smoothing transition regression method for the empirical estimation of the CRP acreage equation. Investigating how crop price variation affect land enrollment through the payments offered to farmers is imperative to provide policies to sustain the ecological and economic benefits obtained from the conservation program.

Our findings suggest that the relationship between CRP rental rate and CRP acreage is nonlinear. In particular, we observe an L-shaped relationship between the estimated elasticity of CRP rental rate on CRP acreage and the transformed crop price index. Subsequently, our findings reveal that the impact of the ecosystem service payment per acre on CRP acreage differ under different crop price regimes. Estimates from the PSTR regression suggest that the effect of the ecosystem service payment per acre on CRP acreage is positive but declines when crop prices rise. This result support the notion that farmers switch to using conservation lands for agricultural purposes when the future expectations from agricultural returns are high. These findings support both anecdotal and empirical evidence that rental payments to farmers encourage CRP participation when crop prices are low but increasing crop prices crowd out of conservation use of land.

Public policies that are environmentally driven depend largely on farmers willingness to enroll in the program to achieve its expected environmental goals. However, these expectations are difficult to achieve as farmers face competition from alternative land use options. Farmers that are environmentally motivated maybe willing to ensure the use of sustainable conservation practices on their lands up to a point beyond which further use of such conservation practices high greater opportunity cost. Identifying these threshold points that characterize the CRP can provide useful information for management decisions. In light of our findings on the diverse payment per acre effects, it is important to consider flexible strategies that incorporate appropriate mark-up fees that can make up for loss in the wake of high crop prices. Alternatively, agencies that manage the conservation program can institute stricter penalty fees to deter non-compliance in situation where expected agricultural net returns are high.

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APPENDIX

Table 1: Summary Statistics

Variable	Mean	St. Dev	Min	Max
Dependent Variable				
CRP Acreage	12294.45	21319.68	0.1	218483
Independent Variable				
Rental Payments per acres per acre	35.91	18.65	0.26	127.95
Population Density	102.06	239.39	0.43	3234.14
Median Household Income per Capita	14365.62	3647.81	3839.23	54992
Farm Earnings	14727.82	14692.49	5.77976	205826
Temperature	12.39	4.38	1.06	25.2
Transition Variable				
Crop price index	109.12	27.57	28.51	235.85

Table 2: Homogeneity tests

	LM_x		LM_F		HAC_x	
m	Test statistics	p-value	Test statistics	p-value	Test statistics	p-value
1	136.6	0.00	44.14	3.06e-11	42.79	6.204e-11
2	152.1	0.00	47.45	4.98e-11	23.00	1.050e-10
3	808.1	0.00	464.6	0.00e+00	150.00	0.000e+00

The table presents the standard L.M.–type and robust (HAC) homogeneity tests with their corresponding p-values in the panel regression of the natural log of CRP acreage and natural log of rental payments per acres (with crop price index as the transition variable) for a balanced panel for the period 1986–2019.

Table 3: Sequence of homogeneity tests for selecting order m of transition function

	LM_x		LM_F		HAC_x	
m	Test statistics	p-value	Test statistics	p-value	Test statistics	p-value
H_{01}	133.6	0.00e+00	129.5	0.00e+00	42.79	6.204e-11
H_{02}	18.63	1.586e-05	18.06	2.148e-05	13.76	2.077e-04
H_{03}	659.5	0.00e+00	639.3	0.00e+00	437.4	0.00e+00

The table presents the sequence of homogeneity tests for selecting order m of transition function their corresponding p-values in the panel regression of the natural log of CRP acreage and natural log of rental payments per acres (with crop price index as the transition variable) for a balanced panel for the period 1986–2019. The listed null hypothesis have the implications $H_{01}: \delta_1^* = 0 | \delta_2^* = \delta_3^* = 0, H_{02}: \delta_2^* = 0 | \delta_3^* = 0,$ and $H_{03}: \delta_3^* = 0$, respectively, in the auxiliary regression (6) with $m = 3$.

Table 4. Parameter estimation of the PSTR model.

Parameters	Regime–Switching Variables	Coefficient estimates
β_1	Payments per acres elasticity	0.29*** (0.0724)
β_2	Payments per acres elasticity under high crop price	-0.0416*** (0.0056)
$\beta_1 + \beta_2$	Total payments per acres elasticity	0.2485*** (0.0695)
	Control Variables	
β_3	Crop price elasticity	-1.164*** (0.4902)
β_4	Farm earnings elasticity	0.0305*** (0.0063)

β_5	Median Household income elasticity	-0.5475*** (0.0515)
β_6	Population density elasticity	-0.5029*** (0.0838)
β_7	Lagged – CRP acreage elasticity	0.5593*** (0.0108)
β_8	Temperature elasticity	0.0898*** (0.0086)
	Model specifications	
c	Transition function threshold parameter	0.1594 (0.0104)
γ	Speed of adjustment of transition function (Slope parameter)	19.8 (1.516)
Observations		**29,818**

The standard errors in the parenthesis are cluster-robust and heteroskedastic-consistent covariance estimators in nature and allow for error dependence within counties. $* \, p < 0.1$; $** \, p < 0.05$: $*** \, p < 0.01$

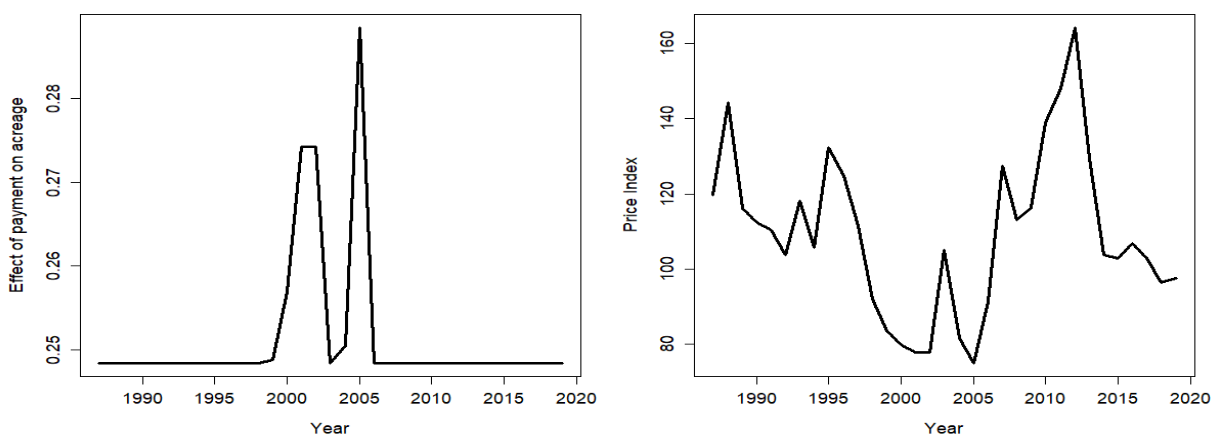

Figure 1: Payments per acres elasticity and crop price trends

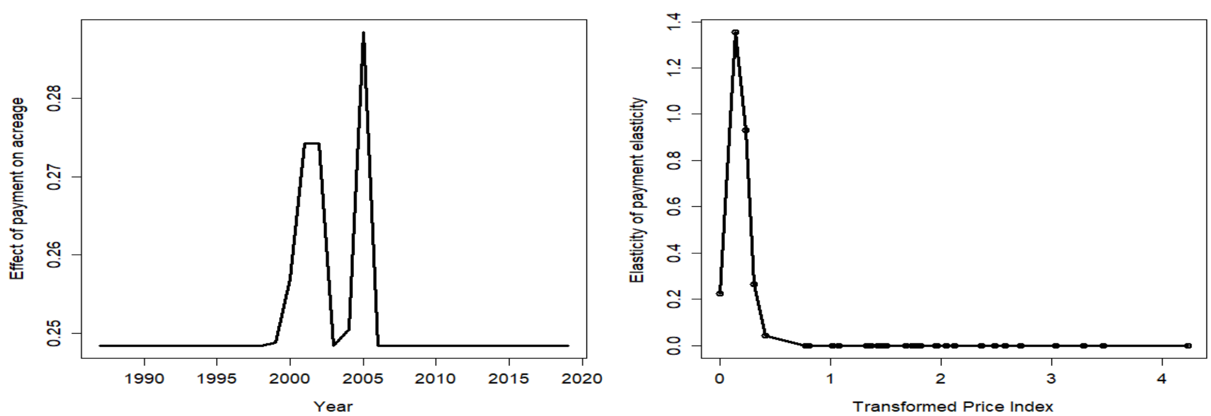

Figure 2: Elasticity of rental payments per acres elasticity versus transformed transition variable and crop price trends