The Impact of Energy Production on Farmland Markets: Evidence from New York's 2008 Hydraulic Fracturing Moratorium

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ABSTRACT

Future conventional and renewable energy production will predominantly occur on farmland, resulting in economic gains as well as potential negative externalities for farmland owners and rural communities. However there is limited research on the economic impact of energy production that takes place on farmland. This study uses the discrete change in expectations caused by the 2008 New York State moratorium on hydraulic fracturing to investigate the net impact of shale gas development on farmland values. We use a difference-in-differences empirical design with a hedonic pricing model. We find that the moratorium led to net economic losses for rural landowners in New York's Southern tier, as reflected in farmland values declining approximately $1,400/acre.

Keywords: Shale gas development, Farmland markets, Marcellus Formation

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1. INTRODUCTION

The U.S. is on its way to becoming a net energy exporter. Most current and planned energy production, whether conventional or renewable, will take place on farmland (Hitaj et al., 2018). However, little is known about how energy production influences farmland markets. Farmland makes up over 80 percent of farm sector assets and serves as a primary source of collateral for farm loans (Nickerson et al., 2012). U.S. energy exports have been fueled by a boom in natural gas production from new technology, such as hydraulic fracturing (DiChristopher, 2018). In 2017 shale gas production accounted for 60% of U.S. natural gas production (EIA, 2017) and 18% of domestic energy production (EIA, 2018). With this growth, there have been multiple debates on the impacts of shale gas development (SGD) on the economy, environment, and social welfare. As such, the impact of SGD on property values has become the focus of a growing body of literature (Muehlenbachs et al., 2015). Other research has considered how areas with energy production activities tend to have increased population, employment, business activities and government revenue in the short term (Weber, 2012; Fetzer, 2014). Hitaj et al. (2018) found that oil and gas payments represent over 6% of net cash farm income and almost 5% of off-farm household wages earned by all U.S. farm operators and landlords in 2014. Payments of this magnitude can influence farmland values as well as rural economies.

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This study estimates the net valuation of future SGD, as reflected in farmland values, using farmland transactions data from New York state from before and after a moratorium was unexpectedly imposed on SGD in 2008 (figure A3).[1] Farmland market impacts are relevant both for the direct influence on agriculture as well as a measurement of the economic impact of energy production. Energy production can provide income for rural landowners and may be an important source of income for farm households (Hitaj et al., 2018). On the other hand, higher farmland prices can increase the capital investment necessary to begin farming or expand existing operations. However, there is limited research on how energy production influences farmland markets. Quantification of the capitalization of SGD into farmland values also contributes to understanding of the economic impacts of SGD for rural landowners, reflecting expected energy production revenues less any costs related to negative economic, environmental and amenity impacts. While farmland values may reflect some of the expected negative externalities of SGD, we expect this to be substantially less than residential property.

There are two major components of compensation payments of SGD: signing bonuses and royalty payments. Signing bonuses can vary from \$50/acre to \$6000/acre (Weidner, 2013). Federal regulations mandate a minimum royalty payment of 12.5% of the value of gas removed, but the negotiated rate could be much higher and is typically based on multiple factors (Weidner, 2013). Brown et al. (2016) estimated that on average, landowners in Marcellus Shale (Pennsylvania) received a 13.2% royalty payment. Other sources of revenue include payments for pipeline construction (Messersmith, 2010) and compressor station construction (Boslett et al., 2016). Harleman and Weber (2017) estimated that an unconventional well would produce \$9.1 million worth of gas and \$774K payments to the local community over its lifespan. The aggregate impact of technological innovation and shale gas development on U.S. equity capitalization is estimated to be \$3.5 trillion since 2012, which suggests that negative environmental effects are offset by the positive employment and stock market impacts (Gilje et al., 2016). The costs of SGD include environmental impacts such as water pollution and air pollution (Caulton et al., 2014; Sovacool, 2014; Howarth et al., 2011), as well as social impacts such as mental distress and conflicts within local communities (Kriesky et al., 2013; Simonelli, 2014).

Several recent studies have focused on local effects of SGD, through analysis of residential housing values. Residential property value primarily reflects the value of buildings, as well as amenities associated with buildings. Muehlenbachs et al. (2015) found that shale gas development can decrease residential property values significantly due to the risk of water contamination. Gopalakrishnan and Klaiber (2013) found that the negative impact of SGD on residential property value depends on proximity and intensity of the nearby shale activity and is transitory. On the other hand, Boslett et al. (2016) showed that the New York State (NYS) SGD moratorium led to a 19%–27% decrease in housing prices in three counties in New York's southern tier. Boslett et al. (2016) studied housing prices in Steuben, Chemung and Tioga county. 'Southern tier' is often used to broadly refer to several southwestern New York counties. Our study includes several counties typically considered to be a part of the southern tier: Allegany, Steuben, Chemung, Tioga, Broome and Chenango For agricultural properties, the land value reflects the present value of the income stream generated from agricultural production, as well as potential non-agricultural influences or income sources (Borchers et al., 2014a). Weber and Hitaj (2015) found farmland in the Barnett Shale (Texas) and the Marcellus Shale (Pennsylvania) experienced significant appreciation in value when there was intense gas leasing and drilling. Weber et al. (2013) showed that U.S. farmland values are positively associated with royalty payments from wind, oil and gas production.

1. Tables and figures denoted as A1, A2,... are available in the online supplemental appendix.

This study makes two major contributions. The first is providing novel and robust evidence of local impacts of SGD on farmland values, which improves understanding of the economic impacts of energy production for rural landowners and the farm sector. To the best of our knowledge, this is the first study focused on the impact of the NYS shale gas moratorium on farmland values and one of the few studies on the impact of energy production on farmland. We use NY farmland transactions data and a difference-in-differences design to quantify the net value of expected SGD in farmland in the southern tier of New York in the late 2000s. Our identification strategy is similar to Boslett et al. (2016), but we focus on farmland and New York state only. Leading up to a SGD moratorium announced July 23, 2008, there was a general expectation that a statewide ban on SGD would not be passed, as reflected by reported investment in farmland and several leases being signed by rural landowners (Jacquet and Stedman, 2011;Wilber, 2014). This natural experiment allows us to quantify price changes for properties most likely to be affected by SGD relative to price changes for properties highly unlikely to have SGD, based on underlying geologic formations that largely follow county boundaries.[2]

The second contribution is in using a machine learning technique–least absolute shrinkage and selection operator (LASSO) regression–to select variables to control for agricultural use value of farmland. Large datasets and complex spatial information are becoming the norm in property valuation research. ZTRAX and other public or private property transaction databases allow researchers to estimate models that contain an unprecedented level of information on property and surrounding characteristics, for example neighborhood attributes or soil properties. While these databases allow researchers to account for previously unobservable property characteristics, standard econometric models often cannot incorporate this new information. Appraisal methods are now regularly augmented by machine learning methods, i.e. Čeh et al. (2018); Lasota et al. (2011); Antipov and Pokryshevskaya (2012), and these methods are useful for informing housing policy (Hu et al., 2019). Machine learning models for hedonic estimation of residential property values have been shown to be useful for variable selection and increasing predictive power (Yoo et al., 2012), but research applications have been relatively rare. In this study, we have a large number of potential control variables for soil properties, but are limited by the number of transactions observed. Use of LASSO allows our hedonic price model to benefit from more robust controls for agricultural use value, while maintaining a tractable and interpretable specification.

We begin with a description of our empirical model and identification strategy, followed by a description of New York farmland transactions and other geo-referenced data used in this study. We next select our preferred model and control variables, then present our results and provide a comparison with findings from other studies and several robustness checks. We find that farmland in the southern tier of New York experienced a value loss of approximately $1400/acre due to the moratorium. This estimate suggests that markets valued future benefits of shale gas production well above costs and a substantial loss of expected wealth for rural landowners due to the moratorium.

2. EMPIRICAL MODEL

We use a hedonic price model, a standard approach in the farmland valuation literature (Nickerson and Zhang, 2014), to model New York state farmland transactions. Hedonic pricing models are based on revealed preferences and assume that the price of a good is a function of the good's characteristics. Rosen (1974) developed the model for differentiated consumer goods

2. Counties near the southern boundary of New York are considered highly productive in shale gas, while the others are not.

and Freeman (1974) constructed a similar model to quantify the marginal effect of environmental characteristics on residential properties' value. By decomposing the price of the good into implicit prices of characteristics of the good, we recover the value of each characteristic of the good. We apply the hedonic pricing framework to farmland prices to incorporate the change in expectation of future SGD. The price function is constructed as: $P_i = P_i(S, G, D)$, where S is a vector of soil characteristics, G is a vector of geographical characteristics or non-agricultural characteristics commonly associated with farmland values, and D an indicator variable for whether shale gas development is feasible for farmland parcel i. We construct our difference-in-differences (DD) design by specifying $E(P_{itm} \mid i, t, m) = \alpha_i + \lambda_t$, where i denotes farmland parcels, t denotes time periods and m takes a value of 1 i the transaction occurred after the moratorium and 0 otherwise. Here we assume that the outcome (farmland price) without any treatment (moratorium) is determined by the sum of regional effect α_i and temporal effect λ_t. Note that, P_{itm} are potential outcomes, we can only observe one or the other. For instance, for a farmland in the treatment group (*fairway* region, see Figure 1), we only observe P_{it1} after July 2008, and we do not see P_{it0} after July 2008.

Next we consider the impact of the moratorium. Assuming $E(P_{it1} - P_{it0} \mid i, t)$ to be a constant, the impact of the moratorium is denoted by M_i. We let $R_i = 1$ if farmland is in the *fairway region* and zero otherwise, then we have:

$$E(P_{it1}) \quad = \alpha_i + \lambda_i + M_i * R_i \tag{1}$$

Thereafter, for the *fairway* region (treatment group) we have:

$$E(P_{it1} \mid i, t = 1) - E(P_{it0} \mid i, t = 0) = \lambda_1 - \lambda_0 + M_i \tag{2}$$

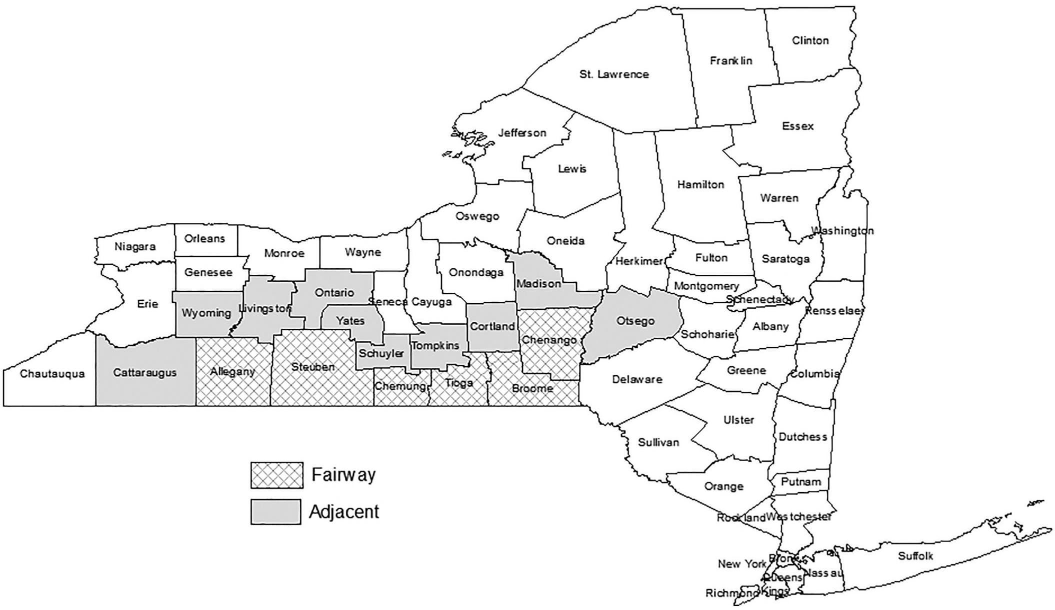
For the *adjacent* region (control group) we have:

$$E(P_{it1} \mid i, t = 1) - E(P_{it0} \mid i, t = 0) = \lambda_1 - \lambda_0 \tag{3}$$

Taking the difference between equation 2 and equation 3, we can obtain the impact of the moratorium, M_i. Here we assume the impact of the moratorium on farmland in the *adjacent* region (control group) is minimal or nearly zero. This is an arguably reasonable assumption, as the shale formation beneath these counties are shallow and thinner (MCOR, 2017). These counties are not considered economically viable for shale gas production, as the geological characteristics of these counties imply much higher costs of SGD than those of the treatment group. Further, many of these counties have high levels of local opposition to SGD and passed local bans against SGD before the statewide moratorium (FracTracker, 2017; Boslett et al., 2016). On the other hand, the highly productive area is contained within the *fairway* region (treatment group), but the boundary of shale formations does not fully extend to county lines—we thus include some areas without shale gas potential into our treatment group (see figure A4). Consequently, this inclusion biases our estimates downwards and our estimates would serve as a lower bound of the net expected economic benefits of SGD plus any negative externalities or impacts in the *fairway* region (treatment group) of New York. This downward bias would be mitigated if land suitable for SGD was more likely to be sold before the moratorium.

The change in expectations caused by the moratorium provides us an opportunity to recover the net value of SGD for an area that was suitable and highly likely to experience SGD. The moratorium likely reduced the possibility of future SGD from a positive (or near-one) number to zero or near-zero, so our estimates will likely be somewhat lower than the true net value of SGD in NY. From 2005, when gas companies started to drill in northeastern Pennsylvania (Carter et al., 2011), they began to approach to landowners and landowner coalitions in the counties that are near

Figure 1: Treatment Region Classifications



the southern boundary of New York, in the hope of signing leases for future SGD (Jacquet and Stedman, 2011). Many leases were signed with landowners in those counties. For example, in May 2008, a group of landowners in Broome County signed a multi-million contract with XTO Energy (Wilber, 2014). Additionally, NYS started receiving permit applications for SGD since early 2008 until the moratorium (Leahy, 2011). Although there was growing excitement regarding the economic benefits of SGD, there were concerns in regard to the environmental consequences and human health risks as well (Wilber, 2014). In July 2008, Governor Paterson approved the NYS SGD moratorium (NY Senate Bill 8169-A), primarily due to environmental concerns. In 2014, NYS placed a ban on SGD.[3] Despite the fact that over 200 towns in New York had passed local ban or moratorium on SGD, many towns in the southern tier of New York are in support of SGD (FracTracker, 2017). 15 towns in the southern tier of New York considered secession due to the ban on SGD (Mathias, 2015). Likewise, most townships that passed local moratorium/ban on SGD are unlikely to experience SGD due to shale formation limitations such as low shale formation thickness and depth (FracTracker, 2017; Boslett et al., 2016).

Although our empirical strategy is similar to Boslett et al. (2016), there are a few critical differences in property type and the underlying assumptions of our empirical strategy. While their study considers residential property, our focus is farmland. Farmland market analysis is highly relevant from an energy development perspective and likely capture more of the direct impact of production than residential property (Hitaj et al., 2018). However, farmland is thinly traded and presents its own unique empirical challenges, such as controlling for agricultural use value. Boslett et al. (2016)'s control group is two counties in Pennsylvania (PA) and treatment is three New York counties: Steuben, Chemung and Tioga. Our study area is physically larger, with 6 counties in the treatment group and 10 in the control. The choice of control group has different implications for potential direction of bias in each study. Our study assumes that SGD is not likely in control counties,

3. We initially considered analysis of the 2014 ban, but did not find any evidence that this ban was unexpected, or more formally, changed expectations of land use or property values.

if violated our estimate would be downward biased. Likewise, Boslett et al. (2016)'s control group assumes a parallel trend for residential properties in PA and violation could lead to their estimate being an upper bound, given the higher level of economic and energy development in PA. In terms of spillovers, PA is downstream from an environmental perspective but NY might experience positive economic spillovers. Given these important differences in property type and assumptions, we believe our study provides complementary information to Boslett et al. (2016).

The following equation is our main econometric specification:

$$P_i = \beta_1 X_i + \beta_2 fairway + \beta_3 PostMoratorium + \beta_{did}(PostMoratorium * fairway) + \varepsilon_i \quad (4)$$

Where P_i is the price of farmland i, *fairway* is a binary variable equal to 1 if the farmland is in the *fairway* region, *PostMoratorium* is another binary variable equal to 1 if the transaction occurred after the moratorium, and X_i are our control variables, including geographic characteristics, soil characteristics and temporal effects. Lastly, ε_i is the error term.[4] We estimate heteroskedasticity-robust/Huber-White standard errors. While many studies routinely cluster standard errors around a particular geographic area (i.e. county, district), Abadie et al. (2017) suggest that clustering is most appropriate to adjust for sampling or experimental design. Given that the SGD moratorium was implemented at the state level and that the land parcel transactions that constitute our dataset do not have a consistent pattern of spatial correlation (see Supplemental Appendix Section A7.1), we do not believe that there is theoretical justification for clustering standard errors. Further, our 16-county study area would be subject to the "small cluster problem" (Cameron and Miller, 2015).

β_1 is a vector of coefficients for control variables and β_2 is the average farmland price difference between the *fairway* region and the adjacent region. β_3 is the average price change for farmland after the moratorium. Our main variable of interest, β_{did}, measures the impact of the moratorium on *fairway* region farmland values, relative to the farmland in the control group. Our expectation for the sign of β_{did} is ambiguous, given three feasible scenarios. First, farmland owners in the *fairway* region might place a very high value on environmental amenities and prefer that there would be a moratorium on SGD. In other words, the environmental loss associated with SGD is greater than the economic gains from SGD. In this case, the β_{did} would be positive. This effect may also be attributable to beliefs related to non-environmental disamenties or other expected negative externalities of SGD (i.e., Jacquet, 2014; Meng and Ashby, 2014; Muehlenbachs et al., 2013). Second, landowners may have expected to receive economic gains, such as royalty payments and signing bonuses from SGD. Assuming they place a higher value on the economic gains over the sum of any negative externalities, β_{did} would be negative. Third, the costs and risks of SGD could happen to be similar to the gains from SGD or landowners were uninterested in SGD. In such a case, β_{did} would be indistinguishable from zero.

3. DATA

We obtained farmland transactions data from New York's Office of Real Property Tax Services, which collects the data from property assessment offices in each county. The full dataset contains farmland transactions from January 1, 1999, to December 31, 2016. For each transaction in our dataset, we have information such as exact sales date, total sales price, acreage and property usage type. In total, there was 486 land transactions classified as agricultural during the study period (October 21, 2007 to April 21, 2009). 142 observations belong to the *fairway* region, and 344 observations belong to the *adjacent* region. The data selected to enter the difference-in-differences

4. Our data did not exhibit sufficient spatial dependency to justify a spatial lag model or correction for spatial correlation of standard errors, for more details see the Supplemental Appendix, Section A.1.

(DD) model includes observations from 9 months prior to the moratorium to 9 months after the moratorium, because price trends (figure 2) suggest that, in the longer term, the parallel trends assumption could be violated. This short time frame might be considered undesirable either because the number of observations is inherently lower or only a short term effect is observed. However, there is a general preference for shorter time periods in the hedonic valuation literature to avoid unobserved changes in markets or, in other words, the underlying hedonic function (Freeman III et al., 2014; Nickerson and Zhang, 2014). The presence of time-varying valuation of attributes can violate the the assumptions of the classical hedonic model in a static setting and bias willingness to pay estimates (Bishop and Murphy, 2019). As such, we prefer an 18-month window, but explore parallel trends and related concerns in detail in our subsequent robustness check section.

We gathered GIS data on potential farmland value determinants from various governmental, commercial and academic sources, including: United States Department of Agriculture (USDA) SSURGO database, NYC OpenData, United States Census Bureau Tiger/Line Shapefiles, New York State GIS data, New York State Department of Environmental Conservation, United States Geographical Survey National Land Cover Database, Cornell University Geospatial Information Repository, and ArcGIS. We use a wide range of information on the soil characteristics for each parcel of farmland being sold, to capture each parcel's agricultural potential and minimize the omitted variables related to potential agricultural productivity. In total, we have 55 parcel specific variables included in our original data set, including several from SSURGO (Soil Survey Staff, accessed in 2017). We also generate several measures of potential non-agricultural uses or influences. Prior studies have shown that distance to natural amenities, metropolitan areas, and hospitals can influence farmland valuation (Borchers et al., 2014a).

Figure 2: Pre- and Post-moratorium Sales Price Trends

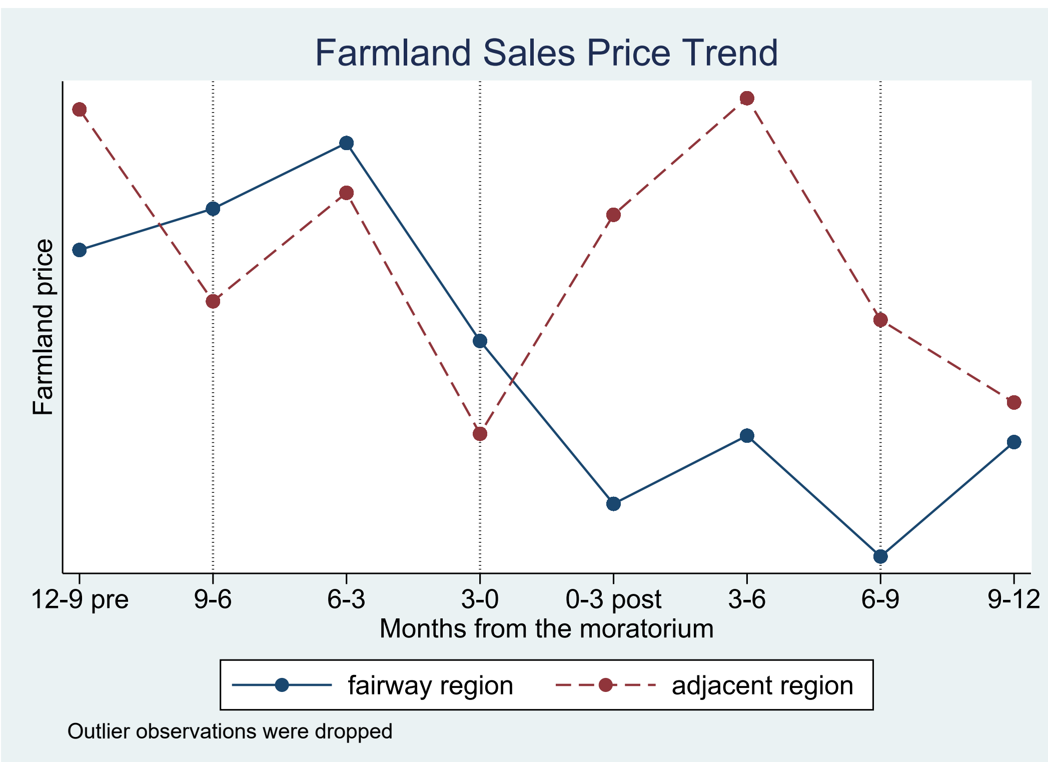


Table 1 presents and summarizes all variables used in our main model. Our data has extreme outliers in price and acreage, which may lead to unrepresentative results. In order to address this issue, we dropped the observations with price in the top and bottom one percentiles. Additionally, we drop parcels that are larger than 5,000 acres.

Table 1: Summary Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Distance to NYC(ft)	486	324890.8	65380.47	194631	458172.7
Distance to the nearest college(ft)	486	20491.45	7929.79	1128.77	40741.12
Distance to the nearest urban area(ft)	486	8651.73	5985.25	0	30905.88
Distance to the nearest hospital(ft)	486	14778.04	6874.74	1912.74	33983.38
Distance to the nearest golf course(ft)	486	8105.03	4094.70	342.77	21311.63
Distance to the nearest EPA site(ft)	486	6010.28	3557.99	245.40	19128.37
Tree-cover rate(%)	486	24.97	19.66	0	85.09
Tree-cover rate^2 (%)^2	486	1009.03	1391.983	0	7240.119
NCCPI map unit percent earthy(%)	486	83.62	4.69	54.11	95
NCCPI map unit percent earthy^2 (%)^2	486	7013.59	768.34	2928.4	9025
Distance to the nearest ethanol plant(ft)	486	95599.56	28019.65	41126.39	158790.8
Thickness of soil components-standard zone 2	486	18.33	1.67	11.41	20
Thickness of soil components-standard zone 2^2	486	338.97	59.69	130.27	400
Thickness of soil components-total profile^2	486	23857.41	8903.94	1542.51	39864.12
Available water estimate-standard layer 5	486	29.79	24.59	0	160
Available water estimate-standard layer 4^2	486	2062.437	2272.375	0.00	20178.58
NCCPI for small grains	486	0.28	0.11	0.013	0.55
Drought-prone	486	0.60	0.39	0	1
Drought-prone^2	486	0.52	0.43	0	1
Soil organic components-standard layer 6^2	486	2.05e+07	1.36e+07	0	2.27e+08
Root zone depth^2 *(cm)*^{2}	486	12833.95	8075.89	727.38	22500
Fairway	486	0.29	0.46	0	1
Postmoratorium	486	0.46	0.50	0	1
*Fairway*Postmoratorium*	486	0.13	0.34	0	1
Price($/acre)	486	2874.52	3650.94	50.83	32000

NCCPI stands for National Commodity Corp Productivity Index

4. MODEL SELECTION

To develop our preferred specification or main model, we must first select control variables to account for agricultural and non-agricultural farmland value determinants. We have over 100 potential control variables[5] representing parcel characteristics, which all potentially contain information about agricultural and non-agricultural farmland uses. A large share of these variables reflect potential soil quality. Soil quality or productivity is highly complex (Doran and Parkin, 1994) and we would like our model to benefit from this granular spatial data that reflects the underlying agricultural potential of farmland. Unfortunately, our study has a sample size that precludes including all potential explanatory variables for soil quality, and many of these variables are highly colinear.

To determine which variables best explain farmland prices, we employ the least absolute shrinkage and selection operator (LASSO).[6] to avoid over-fitting and maintain parsimony. A

5. Includes interactions, squared terms, year effects, etc.

6. Net elastic regression and ridge regression were also executed. However, ridge regression tended to shrink coefficients of correlated variables toward each other. For instance, in an extreme case of k identical independent variables, each of them should get the same coefficient with 1/k size that any single one would get if fit alone (Friedman et al., 2010) Consequently, ridge regression would not serve our purpose of minimizing the number of control variables. On the other hand, although net elastic regression produced some zero coefficients, it did not effectively reduce the number of minor control variables. As a result, we use LASSO regression. Ridge and net elastic regression results are reported in table A4. We use a STATA package developed by Wilbur Townsend.

LASSO regression minimizes the residual sum of squares, subject to the sum of absolute value of the coefficients less than a constant, and this constraint tends to produce some coefficients that are exactly zero, and hence gives interpretable models (Tibshirani, 1996). The parameter λ of the LASSO regression, which was the lagrange multiplier of the minimization problem, was tested and determined by a ten-fold cross validation process. We run these regressions with farmland sales data from 1999 to 2016 in New York (18,616 observations in total) to narrow down the range of control variables we consider for our models.

Full results of the LASSO regression are reported in Table A4, of which 23 variables take on non-zero coefficients. We exclude from our main specification control variables that are not economically relevant for New York state, even though they were chosen by LASSO.[7] We also exclude the squared terms of *Distance to the nearest EPA site*, *Distance to the nearest ethanol plant*, *Distance to NYC* due to the severe multicolinearity problem caused by these terms (original terms are included in the model). Further, we include *Distance to the nearest urban area* to control for potential urban influence on farmland, even though it was not selected by LASSO, as its inclusion is supported by economic theory and is considered to be highly relevant for farmland valuation (Borchers et al., 2014a). Last, although not included in our LASSO regression, we add year dummies to our main specification to control for underlying temporal changes. We report the trends for our LASSO-selected control variables in tables A6–A8, for our pre and post-moratorium periods, as well as 2005 and 2011. We first note that although not completely stable, the vast majority of these variables do not appear to vary widely within-region, over time. However, when we compare the differences between regions, we find that most of these variables are statistically different (columns 1–4, table A8), suggesting that they are important control variables. We also test the difference in means between regions over each variable in the long run (column 5), and most cases they are also statistically different, supporting our preference for a relatively short study period. However, we find that the differences in means of control variables between regions 9 months pre- and post-moratorium (column 6), are largely stable, with only a handful of variables having a statistically different trend. Given that farmland markets are thinly traded and influenced by many factors, we are not surprised that are control variables exhibit some volatility. We further explore indicators of potential violations of the parallel trends assumption in our results section.

To illustrate the degree to which using LASSO helps us select appropriate control variables, we estimate an additional specification using (1) all variables representing non-agricultural influences and (2) NCCPI and NY soil group number[8] as proxies for soil quality. This allows us to compare our results based our LASSO-guided preferred specification to a "conventional specification". Empirical studies of farmland value often use a soil quality index, such as NCCPI, to account for the agricultural value of potential of farmland, as well as a few other variables that represent agricultural use value, i.e. slope, share of forest area, soil moisture level (Zhang and Nickerson, 2015; Bigelow et al., forthcoming; Ifft et al., 2018).

5. RESULTS AND DISCUSSION

Table 2 presents the results of our difference-in-differences (DD) model with and without controls. We use observations from 9 months prior to and after the moratorium to avoid potential violations of the parallel trends assumption. Overall, the results reported in table 2 provide strong

7. We exclude soil productivity for cotton (NCCPI-CO), because there is no major cotton production in New York, as New York's climate and rainfall is unsuitable for cotton production (Glade Jr et al., 1996).

8. This variable is similar to NCCPI but was developed for New York agricultural land tax appraisal.

evidence that, for the six counties in New York's southern tier (the *fairway* region), among all observable competing factors, that rural landowners would have financially benefited from SGD. Unfortunately, we can only identify the aggregate SGD net impact, which clearly indicates that economic gains dominate any potential losses.

Specifications with different controls for parcel characteristics do have somewhat similar results, especially in terms of statistical significance and magnitude of our variable of interest. The DD coefficient from the specification using all potential controls (main model) is around –$1,400 and is statistically significant at $\alpha \leq 5\%$ level. If well life was one decade, this would be equivalent to the net present value of annual payments of $195 per acre at a 6% discount rate.[9] While actual payment levels would vary widely, this level of payment is reasonable given that all land may not have been suitable. The average size of a farmland parcel in our sample is about 78 acres, and this would translate into an average annual payment per parcel of $15,210.[10] In 2014, Marcellus Shale landowners received $3.94B (estimated) royalty payment from 115,527 leases, an average of $34,104 royalty payment per lease.[11]

In the second column (Conventional model), instead of using control variables guided by the LASSO results, we estimate a standard farmland valuation model, as discussed in the Model Selection section. Our estimate of the impact of the moratorium is larger under this specification, by more than $200. This result suggests that using control variables selected by LASSO, including several that represent soil quality, better serves our identification strategy and leads to a more conservative estimate of the impact of the moratorium. The larger estimate implies that shale gas development was more likely to have occurred on land that was more favorable for agricultural production. In other words, the estimate from our preferred specification (column one) is less likely to reflect the agricultural use value of farmland.

Table 2: Results of Main Model with Different Control Variables

	Main model	Conventional model	No controls
*Fairway**PostMoratorium	**–1401.19****	–1,628.26**	–1766.19**
	(715.84)	(784.31)	(736.66)
LASSO-guided controls	**Y**	N	N
Conventional controls	**N**	Y	N
Temporal Controls	**Y**	Y	N
Observations	**486**	486	486
R-squared	**0.20**	0.16	0.014

Robust standard errors are shown in parentheses; asterisks denote *** $\alpha \leq 0.01$, ** $\alpha \leq 0.05$, * $\alpha \leq 0.10$.

We can perform a back-of-the-envelope calculation for aggregate impact on farmland owners, albeit with strong assumptions. *Fairway* county farmland acreage of 948,600 acres from the 2007 USDA NASS Census of Agriculture implies a total net loss in value for farmland owners from the moratorium of about $1.35 billion. So far two New York state-sponsored economic development programs for the southern tier of NY have been established, presumably to at least partially offset the economic impact of the ban on SGD in NY. The Southern Tier Agricultural Enhancement Program paid out approximately $22.6 million to farmland owners in the southern tier from August 2016 to September 2017, with plans for $25 million total. Another $100 million is intended to be

9. In reality well life may be as short as 7–8 years and as long as 2 decades. Payments would likely be higher in earlier years; for instance, signing bonus is paid upon signing the lease.

10. Based on $195 per acre present value of annual payments.

11. Data from www.drillinginfo.com.

invested into farmland and agricultural businesses in the southern tier through the Upstate Revitalization Initiative (URI), from 2015 to 2020.[12] Additionally, the state government estimates the URI will leverage $525 million of private investment (REDC, 2015). The magnitude of economic loss implied by our model is broadly comparable to these development programs.

Our estimates of farmland value impact may not reflect the entire present value of SGD. First, there was some uncertainty regarding future SGD in NY before the moratorium; hence the true net value of SGD in NY was likely not fully capitalized into farmland prices before the moratorium. Secondly, our estimates do not include impacts of the moratorium on non-farmland properties, and Boslett et al. (2016) found that the SGD moratorium caused loss in value for residential properties as well. Third, some farmland in the *fairway* may not be suitable for SGD. This potential downward bias may be mitigated if land that was more suitable for SGD was more likely to be sold pre-moratorium.

The direction of the coefficients on controls variables (Table A2) are largely in accordance with economic theory and prior farmland valuation studies. Coefficients on *Distance to NYC* are negative and statistically significant at $\alpha \leq 10\%$ level, indicating being nearer to NYC results in higher farmland valuation. Similarly, statistically significant coefficients on *Distance to the nearest urban area*, are also negative, indicating urban development pressure and option value or amenities associated with urban areas have a positive impact on farmland value, consistent with Borchers et al. (2014a)'s and Flanders et al. (2004). The coefficient on *Tree-cover rate* is also negative, indicating that farmland with higher tree-cover rates tend to have lower values.

Our results are largely consistent with prior, related studies. Using a similar identification strategy, Boslett et al. (2016) found that the moratorium led to a 19%–27% decrease in housing prices in the southern tier of NYS. In our study, the net valuation of SGD is estimated to be approximately $1,400/acre in the *fairway* region, approximately 40% of the average farmland value in the region in 2008. There are two main reasons that we expect the net valuation of SGD to be relatively larger for farmland compared to residential properties. First, SGD largely occurs on farmland, so farmland should reflect the direct economic gains. Second, farmland usually has fewer improvements and generally has a lower price per acre compared to residential properties in the same area. Third, prior studies have demonstrated that environmental and human health risk is the primary risk and cost of SGD, and the environmental risk such as water contamination is considered low and insignificant if the shale gas well is 2km farther away from a property (Muehlenbachs et al., 2013; Meng and Ashby, 2014). Farmland owners do not necessarily live on or near their farmland. Further, 37% of farmland is rented in NYS (NASS, 2012).

Weber and Hitaj (2015) found that farmland in northeastern Pennsylvania experienced an appreciation of 50% (or approximately $1,850/acre) in value when large scale SGD started in the region in 2007. From a theoretical perspective, the net valuation of SGD should be higher in northeastern Pennsylvania than its counterpart in the southern tier of New York State, because the Marcellus Shale formation is slightly deeper and thicker in the Pennsylvania side, which can result in higher production rates if wells are properly stimulated (MCOR, 2017). In other words, SGD in Pennsylvania may provide a better economic return to landowners, while the environmental risks and costs are commensurate. Furthermore, Pennsylvania generally has a longer history in energy production, especially in SGD. NY never has had SGD; the moratorium only changed expectations for future SGD.

12. The state government has invested $48.8 million by 2019, but we do not have information regarding the size of leveraged private investment.

5.1 Robustness checks

In this section, we consider potential issues with our methodology and data that could influence our results. A few critical assumptions are inherent to our difference-in-differences identification strategy, namely assignment of treatment and control groups and the parallel trends assumption. We also consider our relatively small sample size and the choice of functional form.

We assume that farmland in the *adjacent* region serves as a reasonably good counterfactual for farmland in the *fairway* region. The classification of our control group (*adjacent* region) and treatment group (*fairway* region) follows the expected productivity of the shale formation beneath New York; usually, the expected productivity is determined by geographical metrics of the local shale formation, such as the shale formation's thickness. In general, thicker and deeper shale formations are more productive than the thinner ones (MCOR, 2017). In particular, thicker shale holds more natural gas and deeper shale tends to be under higher pressure, which increases well productivity (Brown et al., 2016). Different geographical measurements can lead to different estimates of shale formation productivity. Generally speaking, the southern tier of New York is considered as the *fairway* (region), which is the highly productive area (Jacquet and Stedman, 2011; CaimanEnergy, accessed in 2017; Boslett et al., 2016). The *adjacent* region contains counties that are geographically contiguous to the *fairway* region. Figure 1 presents the classification of these two regions.

While we are unable to access data on shale depth and analyze our data by this important metric, we can select an alternative control group. While any "non-adjacent" control group would be less similar to the treatment group and hence be more subject to the influence of unobservable parcel characteristics, the alternative control would likewise would be less subject to spatial spillovers. The alternative control group we use is the "North Country" or several counties in northeastern New York (figure A5).[13] The main advantage of using this control group is that this region does not have known, extractable shale deposits (Figure A7). Thus, the moratorium should not affect this region. Moreover, the North country is sufficiently far from the fairway region that spillover effects (if there are any) of the moratorium would be arguably minimal. Other regions, including the Hudson Valley, Western New York, the Finger Lakes, Central New York, and the Mohawk Valley, are adjacent to at least some *fairway* counties (see Figure A5). The Capital Region has had stronger economic development than than other rural regions (McMahon, 2020), making it less desirable as a control group. The disadvantage of the North Country as control group is also obvious: these two regions may not share much in common, especially when it comes to unobservable farmland value determinants. While the North Country, as well as any other region, is not perfectly comparable to the *fairway* counties, they do share some general characteristics in areas relevant to farmland values. Both regions have experienced a long term decline in dairy production, which contributes over half of all farm revenue in New York state (Ifft, 2020). Further, the north country is somewhat similar to in terms of economic development and a general trend of declining population (Schultz, 2019). While the Adirondack Park is located within the North Country, we largely do not observe farmland sales within its boundaries. Summary results are presented in table 3 and full results in table A5. These results are similar to those of our preferred specification.

Although we cannot explicitly test the parallel trend assumptions, as a first step we graphically analyze key trends. Our price trend graph suggests that a nine-month inclusion of pre-moratorium data serves this assumption the best, using an approach similar to Boslett et al. (2016)

13. The north country region includes Clinton County, Essex County, Franklin County, Jefferson County, Lewis County, St. Lawrence County and Hamilton County.

Table 3: Additional Specifications

	18 months span	18 months span (Log-Linear Model)	48 months span	48 Months Span (NC Control)	18 Months Span (NC Control)	Urban subsample	Rural subsample
*Fairway**PostMoratorium	**–1401.19****	–0.28*	–1026.80*	–1300.01**	–1331.32*	233.19	–1238.63
	(715.84)	(0.15)	(547.43)	(602.97)	(764.42)	(925.65)	(940.82)
Property Characteristics	**Y**	Y	Y	Y	Y	Y	Y
Temporal Control	**Y**	Y	Y	Y	Y	Y	Y
Soil Characteristics	**Y**	Y	Y	Y	Y	Y	Y
Observations	**486**	486	1,298	886	311	237	249
R-squared	**0.20**	0.22	0.09	0.07	0.08	0.25	0.26

Robust standard errors are shown in parentheses; asterisks denote *** $\alpha \leq 0.01$, ** $\alpha \leq 0.05$, * $\alpha \leq 0.10$.
NC control indicates using the north country region as the control group.

(Figure 2). Additionally, we added interaction terms of region and year dummies to our preferred specification and estimated it for years 1999–2007.[14] Test results for statistical difference of the year-region interaction variables in Table 4 generally support our argument that the parallel trend assumption may be violated if we go beyond nine-month pre-moratorium period. Moreover, we also tested region-year interaction terms only with 2005–2007 data. Test results are shown the the bottom part of Table 4. The test statistics increase slightly and suggest that it is not safe to go beyond nine-month inclusion of pre-moratorium data. However, if our results are too sensitive to this relatively short-term cutoff, it may raise concerns about the transitory effect of our main result. We set up an additional specification covering 48 months (2 years before and after moratorium) and estimated our preferred specification with different control groups. The results reported in Table 3 maintain statistical significance and are only marginally smaller than our main result.

Table 4: Test for Region-year Effects

year	1999	2000	2001	2002	2003	2004	2005	2006	2007
F-Statistics	3.77*	0.18	5.25**	11.85***	0.12	18.88***	6.15**	4.75**	3.75*
Probability	0.052	0.669	0.022	0.0006	0.733	0.000	0.013	0.029	0.052
F-Statistics	—	—	—	—	—	—	7.17***	6.77***	5.62**
Probability	—	—	—	—	—	—	0.007	0.009	0.018

H_0: $\beta_2 = \beta_3$

In addition to price trends, we also graphically examine trends in agriculture and housing values across the study area. The primary income stream of farmland is from agricultural production (figure A2). Another concern is that the moratorium occurred shortly after the 2007 real-estate market crash. The two regions may have had different reactions to the 2008 recession. We consider housing prices trends of both regions (figure A1) using county-level Housing Price Index data from the Federal Housing Finance Agency. The trends shown in figures 2, A1 and A2 are similar across both regions, and do not provide evidence that would contradict the parallel trends assumption of our DD design. However, visual analysis is inherently subjective and we cannot disprove trends unrelated to our treatment or these key farmland value drivers.

We conduct additional analysis to address concerns that the southern tier of New York is a relatively economically depressed region and could possibly have experienced a larger negative impact from the (concurrent) 2008 recession. In this case, the estimates from our main model could re-

14. Formally, we estimate the following model: $P_i = \beta_1 X_i + \beta_2 (t_i * adjacent) + \beta_3 (t_i * fairway) + \varepsilon_i$, using notation from Equation 4 and t_i to represent year effects.

flect the recession rather than the shale gas moratorium. A common finding in the farmland valuation literature is that farmland prices are higher near urban areas, reflecting the option value for future residential or commercial development as well as urban-related amenities (Plantinga and Miller, 2001; Livanis et al., 2006). As such, the recession may have lowered the level of 'urban influence' that is typically priced into farmland prices. If our main finding only holds in more urban-influenced area, it would be difficult to argue that price drop was attributable to the SGD moratorium. To test for this potential issue, we split our sample into two subsamples following the characterization of economic regions of NY by the Rockefeller Institute (Schultz, 2019). Particularly, observations from Cattaraugus, Wyoming, Schulyer, Cortland, Otsego, Chenango, Allegany and Steuben are in the rural subsample, and observations of the rest of the sample constitute the urban subsample. Then we estimate our preferred specification with two subsamples. The results are presented in table 3 suggesting that these smaller subsamples lack power, as our estimates lack statistical significance. However, the relative magnitude of our DD coefficients for rural and urban areas suggests that land market activity in rural counties is driving our main result. In other words, we find no evidence that relatively weaker urban economic activity in fairway counties is associated with our main result. This result may also suggest that rural land is preferred for SGD or that negative factors associated with SGD were more prominent near urban areas. While it is beyond the scope of our data and methodology to further explore these forces, neither interpretation is surprising.

Lastly, we test some additional modeling choices made for our preferred specification. Given that we don't have repeated sales or a parcel-level panel (Kuminoff et al., 2010), we estimate linear models in table 2. In table 3, we report our preferred specification estimated using a log-linear model. The reported coefficient suggests a decrease in farmland value of 28% and is consistent with our preferred specification. Given the relatively small sample size of our main specification, we also performed a non-parametric bootstrap procedure, with 1000 replications recommended by Mooney et al. (1993). This allows us to obtain a percentile based 95% confidence interval, in the case of non-normality associated with our estimates of interest. The percentile confidence interval constructed by the bootstrap procedure (Table 5) is similar to the results of our preferred specification.

Table 5: Alternative Construction of Confidence Interval by Bootstrap

	Observed Coefficient	Bias	Bootstrap Std. Err.	[95% Confidence Interval]	
Fairway*PostMoratorium	–1401.19	–14.48	701.72	–2776.54	–25.84(N)
				–2859.76	–157.17(P)
				–2909.08	–233.12(BC)
				Observations	486
				Replications	1000

(N)Normal Confidence Interval, (P) Percentile Confidence Interval, (BC) Bias-Corrected Confidence Interval

We have a few remaining concerns regarding the underlying assumptions of our study. First, although we provide evidence that the parallel trend assumption of our DD model is valid, we cannot observe the "no moratorium" scenario. If the underlying trend of either the *fairway* region or the *adjacent* region changed after July 2008, in absence of the impact of the moratorium, the change would violate the theoretical foundation of our DD model and the accuracy of our results. While we test for several likely violations to this assumption, we cannot absolutely prove this assumption is true. Second, prevalent split estates could distort the interpretation of our results as well (Boslett et al., 2019). For a split estate, the landowner only owns the surface rights of the property, and the mineral rights are sold separately. Split estates can be common in areas with a long history of energy production, such as western Pennsylvania and Texas (Kelsey et al., 2011). On the other hand, researchers have shown that split estates are relatively uncommon in the northeastern Marcellus Shale (Weber and Hitaj, 2015; Fitzgerald et al., 2014). Considering most farmland owners in New York likely hold mineral rights and would receive payments from SGD; our study is more likely to recover the net valuation of SGD.

6. CONCLUSION

Energy development has large economic, social and environmental impacts on rural areas, and the agricultural sector in particular. This study quantifies the net economic value of expected SGD, as capitalized into New York farmland values. We employ a difference-in-differences model that takes advantage of the unexpected imposition of the 2008 New York State moratorium. To the best of our knowledge, this is the first empirical study that evaluates the impacts of the shale gas moratorium on farmland values in New York State. Generally, prior studies have focused on residential properties or properties in other states/areas. We use a LASSO estimator to select controls for agricultural use value of farmland from a large set of parcel-level soil characteristics. Our results are robust to a number of different specifications, including lengthening the study period, accounting for areas more likely to be influenced by the concurrent recession, and an alternative control group. We find that the New York State moratorium on SGD substantially influenced farmland values, with an average decline of about $1,400 per acre in *fairway* counties. This magnitude is consistent with related studies and potential income from shale gas production.

We cannot decompose the net impact of the moratorium, which would provide a better understanding of the benefits and costs of SGD. Also, we do not control for shale depth or water source because of data limitations. Prior studies have shown that groundwater dependent residential properties experience a larger, negative impact from SGD. Accounting for water source may shed light on other aspects of the impact of SGD on farmland value, although this is likely more of an issue for residential property. Our results likely serve as a lower bound for the net present value of SGD at the time of the 2008 moratorium, due to our differences-in-differences design assuming that control counties have zero probability of SGD. We also cannot control for spillovers from shale gas production in Pennsylvania. The Southernmost areas of our study region would be more likely to benefit from SGD due to depth and suitability, but they also would be more likely to experience economic spillovers. While it is difficult to disentangle these positive effects, Pennsylvania would be considered downstream (Arthur et al., 2010) of New York, so we don't expect large negative environmental spillovers. Further, farmland may be less subject to economic spillovers than residential properties.

Given the high likelihood of continued nonrenewable and renewable energy production on farmland, it is important to understand the implications of growing energy development for rural landowners, farmland markets, and the agricultural sector in general. Renewable energy production, especially solar, will likely have a much larger land footprint than oil and gas production, and accordingly have a different impact on agriculture. Future studies should consider potential direct impacts on land values, as well as indirect impacts on farm income and investment, of different types of energy development. Disentangling capitalization of economic benefits from capitalization of environmental impacts and disamenities in rural areas is another important area for future research. State and local energy development policies vary from promotion to discouragement (for example, Borchers et al., 2014b); likewise states also have varied approaches to land use, conservation, and farming. As agriculture and energy production become increasingly intertwined, research on the broad impacts of different energy development policies would inform private and public decision-making.

The expected financial benefits from SGD in 2008 outweighed farmland owners' expectations for any negative environmental, economic and social consequences that would be capitalized into farmland values. Our results imply an approximate magnitude of over $1 billion of wealth lost for farmland owners, if our estimates are assumed to hold for all farmland in *fairway* counties in 2007. This magnitude is consistent with the local response to the moratorium in New York's southern tier, as well as programs designed to mitigate its impact. These estimates of economic impact alone *do not* constitute an argument for shale gas development in New York state or other areas. It is beyond the scope of this study to address total social welfare impacts of SGD in New York state and associated stakeholder preferences. However, we advance understanding of the large economic stakes in policy debates on energy development, especially from the perspective of the agricultural sector and rural land owners.

Supporting materials, including figures and tables referenced as A1, A2,... can be found in the online supplemental appendix, available at https://doi.org/10.5547/01956574.42.3.jiff.

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