

# Internet Appendix

for

## Strategic Learning and Corporate Investment

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This Internet Appendix reports results that are mentioned but not tabulated in the main paper. We report 2 figures, and 7 tables, as outlined below:

1. Figure [IA.1](#): Average Life of Wells as of January 2020

Reference in the main paper: “70% of wells drilled in the first year of the sample were still active in 2020, with an average age of 13 years. For a more complete picture of the wells’ life expectancy per vintages, see Internet Appendix Figure IA.1.” (Section 3.3 Footnote 14)

2. Figure [IA.2](#): Rig Utilization Rate

Reference in the main paper: “This distance, when branching in all directions, mimics the size of a township; however, as we show in Internet Appendix Table IA.1, our results are not sensitive to this particular choice.” (Section 3.3 Footnote 11)

3. Table [IA.1](#): Alternative Distance Definitions for Peer Firms

Reference in the main paper: “This distance, when branching in all directions, mimics the size of a township; however, as we show in Internet Appendix Table IA.1, our results are not sensitive to this particular choice.” (Section 3.3 Footnote 11)

4. Table [IA.2](#): Indicator Variable Approach to Measuring Potential Information Spillover  
Reference in the main paper: “The continuous measure of available information spillover most closely matches the model in Chamley and Gale (1994). However, our results are not sensitive to this modeling decision. Internet Appendix Table IA.2 reports specifications that use an indicator variable equal to 1 for projects with any positive number of peer options. The results in these tests are quantitatively and qualitatively similar to our main results below.” (Section 5.1 Footnote 16)

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5. Table [IA.3](#): Alternative Model Specifications

Reference in the main paper: “Further, Table IA.3 shows that our main results are robust to alternative econometric specifications such as an OLS or Probit model.” (Section 5.1 Footnote 16)

Reference in the main paper: “Internet Appendix Table IA.3 shows are results are qualitatively robust to alternative specifications, such OLS and Probit, in the second-stage.” (Section 6 Footnote 24)

6. Table [IA.4](#): Cox Models with Standard Errors Clustered at the Firm Level

Reference in the main paper: “Wells in the same county are likely to share similar characteristics and thus, face a similar probability of being exercised. Internet Appendix Table IA.4 shows that our inferences are not sensitive to this particular choice of cluster level.” (Section 5.1 Footnote 17)

7. Table [IA.5](#): Robustness to the Reduced Sample with Data on Historical Landownership

Reference in the main paper: “This data covers nearly 80% of our main sample. To ensure consistency, Internet Appendix Table IA.5 shows the results from reduced-form Cox models on the reduced IV sample are quantitatively and qualitatively similar.” (Section 6 Footnote 19)

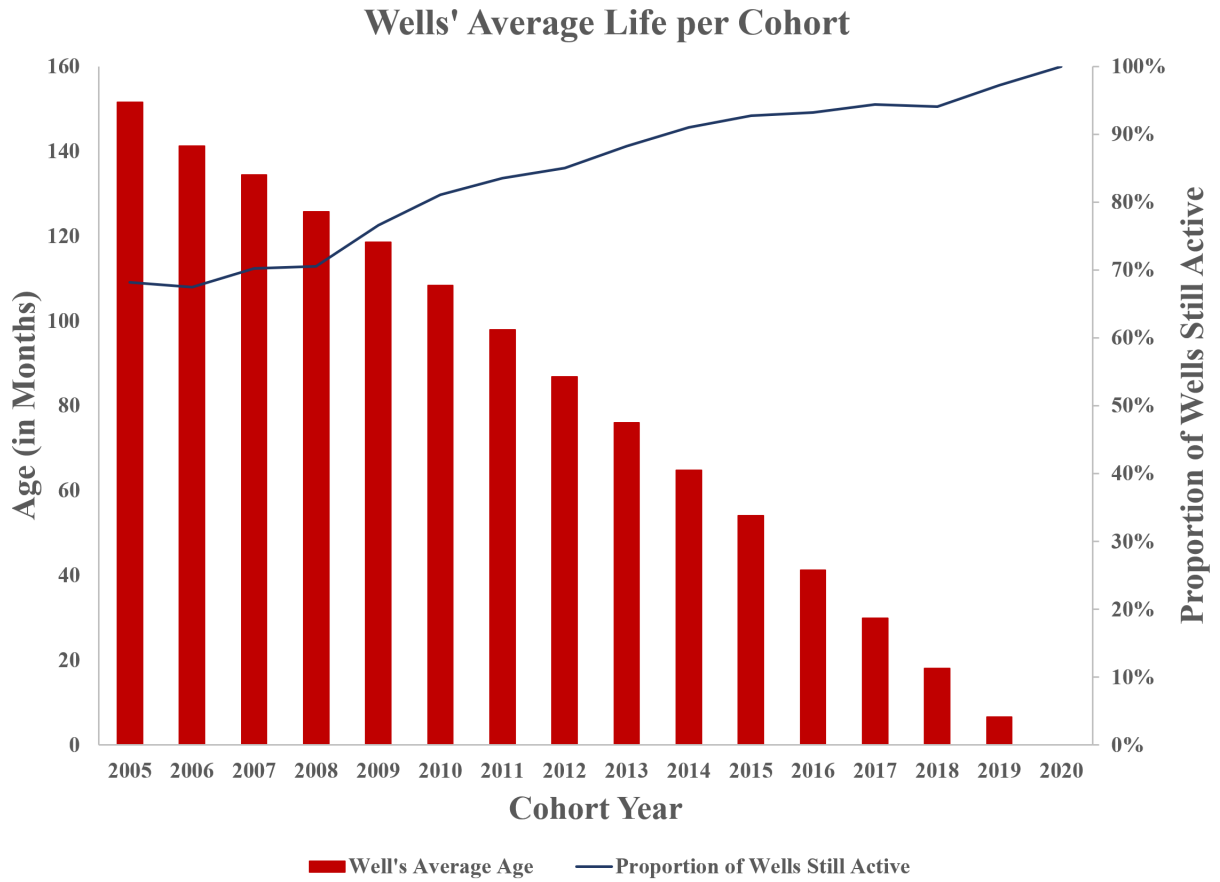
8. Table [IA.6](#): Landownership Fragmentation Through Time

Reference in the main paper: “Figure 8, Panel A presents the visual depiction of the relationship, while Internet Appendix Table IA.6 reports regressions that suggest the number of historical landowners explains as much as 45% of the variation in contemporaneous landowners within a county.” (Section 6)

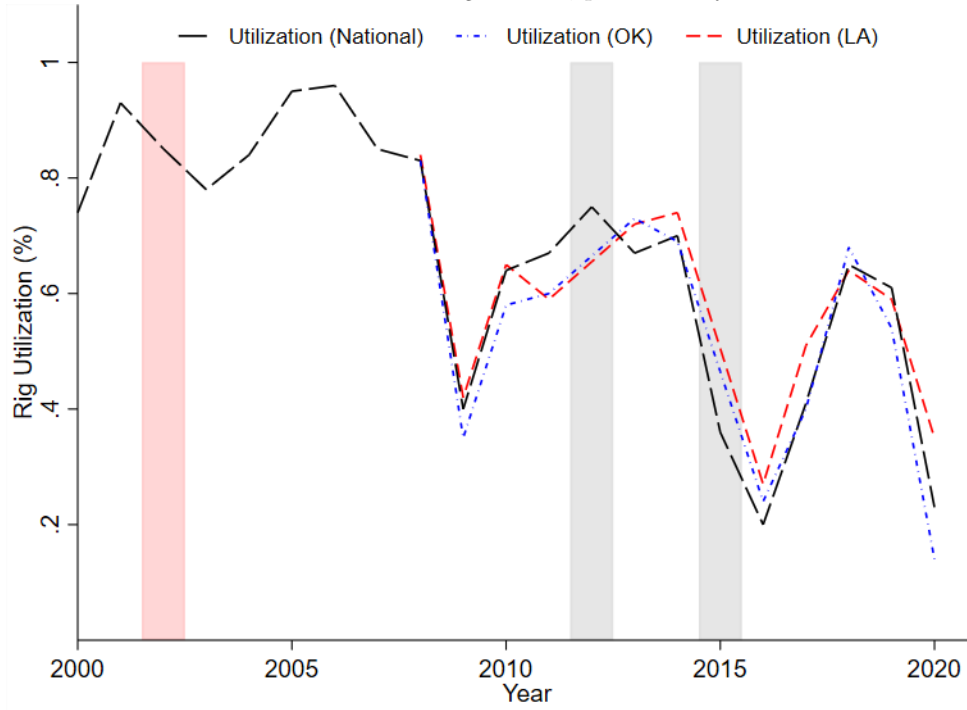
9. Table [IA.7](#): Alternative Two-Stage Instrumental Variables Cox Model Specification

Reference in the main paper: “In Internet Appendix Table IA.7, we verify that our instrumented results are robust to excluding the extreme value of the historical land ownership data.” (Section 6 Footnote 21)

**Figure IA.1: Average Life of Wells as of January 2020.** This graph shows the average age of wells drilled during a specific year, as well as the proportion of those wells that are still in production.



**Figure IA.2: Rig Utilization Rates.** This graph shows the average rig utilization rate at the national level, as well as for Oklahoma and Louisiana separately. Shaded regions indicate the particular year is interpolated from the two surrounding years at the national- (red shading) or state-level (gray shading). Data on rig utilization is taken from the *Annual Rig Census*, produced by National Oilwell Varco.



**Table IA.1: Alternative Distance Definitions for Peer Firms.** This table reports the results of Cox survival models in which the failure event is the drilling of a section’s infill well (the exercise of the section’s real option). The sample includes section-month observations over the period of 2005 through 2020. The main independent variable of interest in this table is *Unexercised Investment Opportunities (Peers)*. However, unlike our main results, we vary the distance used to define a firm’s peers. In particular, in Model (1), we define *Unexercised Investment Opportunities (Peers)* to be the number of real options held by a firm’s peers and located within 2 miles of the section of interest. Likewise, in Models(2) and (3), we define this distance to be 3 and 4 miles, respectively. Data on horizontal wells are from DrillingInfo, while data for the remaining covariates are taken from Bloomberg, St. Louis Federal Reserve Bank, and publicly available firm reports. All variables are defined in Table A1 in the main paper. Robust standard errors, clustered at the county level, are reported in parentheses. \*, \*\*, and \*\*\* denote significance at the 10%, 5%, and 1% level, respectively.

Peers Distance Definition =	Hazard Model for Project Exercise					
	(1)		(2)		(3)	
	2 Miles		3 Miles		4 Miles	
	Estimates	HI(%)	Estimates	HI(%)	Estimates	HI(%)
Unexercised Investment Opportunities (Peers) <sub>j,t</sub>	-0.065*** (0.016)	-6.28	-0.037*** (0.010)	-3.62	-0.015*** (0.005)	-1.54
Cumulative Number of Well’s Drilled <sub>j,t</sub>	0.049*** (0.004)	5.01	0.050*** (0.004)	5.18	0.049*** (0.004)	5.03
Unexercised Investment Opportunities (Own) <sub>j,t</sub>	-0.049*** (0.009)	-4.78	-0.051*** (0.010)	-4.99	-0.047*** (0.009)	-4.59
Portfolio Concentration <sub>i,t</sub>	0.095 (0.168)	10.02	0.076 (0.168)	7.94	0.088 (0.169)	9.23
Mean Distance Between Options <sub>i,t</sub>	-0.069** (0.034)	-6.68	-0.074** (0.034)	-7.17	-0.072** (0.034)	-6.92
Firm Skill Level <sub>i,t</sub>	-0.193** (0.083)	-17.53	-0.192** (0.083)	-17.48	-0.193** (0.083)	-17.55
Royalty Rate <sub>j,t</sub> (%)	0.574 (0.677)	77.58	0.582 (0.673)	79.01	0.578 (0.686)	78.26
Well Lateral Length <sub>j,t</sub> (1,000 ft.)	-0.013 (0.020)	-1.34	-0.012 (0.020)	-1.22	-0.011 (0.020)	-1.10
First Well’s Market Value <sub>j,t</sub>	0.206*** (0.061)	22.90	0.207*** (0.061)	23.00	0.207*** (0.062)	22.95
Peers’ Wells’ Value <sub>j,t</sub>	0.057*** (0.014)	5.87	0.058*** (0.014)	5.97	0.057*** (0.014)	5.81
Oil-to-Gas Ratio <sub>j</sub>	0.344*** (0.124)	41.02	0.340*** (0.124)	40.51	0.343*** (0.126)	40.89
Drilling Cost <sub>j,t</sub>	-0.038 (0.031)	-3.77	-0.039 (0.030)	-3.84	-0.040 (0.031)	-3.90
Futures Price <sub>t</sub>	0.009*** (0.003)	0.90	0.009*** (0.003)	0.90	0.009*** (0.003)	0.89
Implied Volatility <sub>t</sub>	-0.022*** (0.007)	-2.15	-0.022*** (0.007)	-2.15	-0.022*** (0.007)	-2.15
10-Year Risk Free Rate <sub>t</sub>	0.179*** (0.057)	19.62	0.176*** (0.057)	19.27	0.180*** (0.057)	19.69
County Strata		Yes		Yes		Yes
<i>Pseudo – Loglikelihood</i>		-17,075		-17,074		-17,084
Wald Chi <sup>2</sup>		1,140		1,105		1,040
Observations		537,093		537,093		537,093

**Table IA.2: Indicator Variable Approach to Measuring Potential Information Spillover.** This table reports the results of Cox survival models in which the failure event is the drilling of a section's infill well (the exercise of the section's real option). The sample includes section-month observations over the period of 2005 through 2020. The main independent variable of interest is  $I(\text{Peers' Options} \geq 1)$ , which is an indicator variable equal to one if the number of real options held by a firm's peers and located within 3 miles of the section of interest is greater than or equal to 1. Data on horizontal wells are from DrillingInfo, while data for the remaining covariates are taken from Bloomberg, St. Louis Federal Reserve Bank, and publicly available firm reports. All variables are defined in Appendix Table A1 in the main paper. Robust standard errors, clustered at the county level, are reported in parentheses. \*, \*\*, and \*\*\* denote significance at the 10%, 5%, and 1% level, respectively.

	Hazard Model for Project Exercise					
	(1)		(2)		(3)	
	Estimates	HI(%)	Estimates	HI(%)	Estimates	HI(%)
$I(\text{Peers' Options} \geq 1)$	-0.107** (0.052)	-10.18	-0.224*** (0.053)	-20.06	-0.204*** (0.051)	-18.46
Cumulative Number of Well's Drilled $_{j,t}$	0.050*** (0.003)	5.12	0.046*** (0.004)	4.66	0.048*** (0.003)	4.87
Unexercised Investment Opportunities (Own) $_{j,t}$	-0.027*** (0.009)	-2.65	-0.034*** (0.008)	-3.34	-0.042*** (0.008)	-4.07
Portfolio Concentration $_{i,t}$	0.219 (0.180)	24.49	0.136 (0.179)	14.61	0.116 (0.169)	12.25
Mean Distance Between Options $_{i,t}$	-0.051 (0.037)	-5.00	-0.057 (0.036)	-5.53	-0.064* (0.035)	-6.24
Firm Skill Level $_{i,t}$	-0.039 (0.057)	-3.86	-0.246*** (0.082)	-21.78	-0.200** (0.082)	-18.13
Royalty Rate $_{j,t}$ (%)	0.661 (0.743)	93.71	0.629 (0.707)	87.56	0.554 (0.690)	73.98
Well Lateral Length $_{j,t}$ (1,000 ft.)			-0.045* (0.023)	-4.42	-0.012 (0.020)	-1.15
First Well's Market Value $_{j,t}$			0.229*** (0.069)	25.77	0.204*** (0.062)	22.61
Peers' Wells' Value $_{j,t}$			0.066*** (0.015)	6.83	0.061*** (0.014)	6.25
Oil-to-Gas Ratio $_j$			0.314** (0.139)	36.85	0.350*** (0.130)	41.90
Drilling Cost $_{j,t}$			-0.021 (0.042)	-2.07	-0.039 (0.031)	-3.84
Futures Price $_t$					0.009*** (0.003)	0.87
Implied Volatility $_t$					-0.022*** (0.007)	-2.14
10-Year Risk Free Rate $_t$					0.182*** (0.059)	20.00
County Strata	Yes		Yes		Yes	
<i>Pseudo – Loglikelihood</i>	-17,295		-17,184		-17,085	
Wald Chi <sup>2</sup>	378		586		1,133	
Observations	537,093		537,093		537,093	

**Table IA.3: Alternative Model Specifications.** This table reports the results of alternative model specifications probing the robustness of our main results. The dependent variable of interest, *Project Exercise* is an indicator variable equal to 1 in the month a section’s infill well is drilled (the exercise of the section’s real option), and zero otherwise. The sample includes section-month observations over the period of 2005 through 2020. The main independent variable of interest is *Unexercised Investment Opportunities (Peers)*, which is equal to the number of real options held by a firm’s peers and located within 3 miles of the section of interest. Data on horizontal wells are from DrillingInfo, while data for the remaining covariates are taken from Bloomberg, St. Louis Federal Reserve Bank, and publicly available firm reports. Data on historical landownership used in the first-stage regressions for Models (2) and (4) are from the Bureau of Land Management (BLM). For brevity, the first stage regressions are not reported. All variables are defined in Appendix Table A1 in the main paper. Robust standard errors, clustered at the county level, are reported in parentheses. \*, \*\*, and \*\*\* denote significance at the 10%, 5%, and 1% level, respectively.

Dependent variable = Model =	Project Exercise			
	Linear		Probit	
	(1)	(2)	(3)	(4)
	Reduced Form	IV	Reduced Form	IV
Unexercised Investment Opportunities (Peers) $_{j,t}$	-0.0002*** (0.0001)	-0.0007 (0.0006)	-0.0112** (0.0049)	-0.0658* (0.0351)
Cumulative Number of Well’s Drilled $_{j,t}$	0.0002*** (0.0000)	0.0003** (0.0001)	0.0108*** (0.0013)	0.0204*** (0.0065)
Unexercised Investment Opportunities (Own) $_{j,t}$	-0.0004*** (0.0001)	-0.0006** (0.0002)	-0.0213*** (0.0044)	-0.0441*** (0.0132)
Portfolio Concentration $_{i,t}$	0.0013 (0.0014)	0.0011 (0.0016)	0.0640 (0.0646)	0.0001 (0.0745)
Mean Distance Between Options $_{i,t}$	-0.0006* (0.0003)	-0.0008* (0.0004)	-0.0347** (0.0142)	-0.0552*** (0.0193)
Firm Skill Level $_{i,t}$	-0.0017*** (0.0006)	-0.0011 (0.0008)	-0.1229*** (0.0384)	-0.0686 (0.0446)
Royalty Rate $_{j,t}$ (%)	0.0022 (0.0030)	0.0029 (0.0027)	0.3161 (0.2586)	0.4024* (0.2117)
Well Lateral Length $_{j,t}$ (1,000 ft.)	0.0002 (0.0002)	0.0001 (0.0003)	0.0200 (0.0133)	0.0131 (0.0185)
First Well’s Market Value $_{j,t}$	0.0023*** (0.0003)	0.0024*** (0.0005)	0.1612*** (0.0241)	0.1533*** (0.0291)
Peers’ Wells’ Value $_{j,t}$	0.0004*** (0.0001)	0.0004*** (0.0001)	0.0290*** (0.0067)	0.0335*** (0.0086)
Oil-to-Gas Ratio $_j$	0.0039*** (0.0011)	0.0037*** (0.0011)	0.2195*** (0.0604)	0.2093*** (0.0583)
Drilling Cost $_{j,t}$	-0.0004 (0.0003)	-0.0002 (0.0003)	-0.0342** (0.0144)	-0.0210 (0.0174)
Futures Price $_t$	0.0002*** (0.0000)	0.0002*** (0.0000)	0.0099*** (0.0016)	0.0129*** (0.0017)
Implied Volatility $_t$	0.0000 (0.0001)	0.0000 (0.0001)	-0.0024 (0.0033)	0.0000 (0.0041)
10-Year Risk Free Rate $_t$	0.0034*** (0.0009)	0.0020** (0.0009)	0.1789*** (0.0426)	0.1033** (0.0426)
County FE	Yes	Yes	Yes	Yes
Observations	537,093	414,176	527,049	405,391

**Table IA.4: Cox Models with Standard Errors Clustered at the Firm Level.** This table reports the results of Cox survival models in which the failure event is the drilling of a section’s infill well (the exercise of the section’s real option). The sample includes section-month observations over the period of 2005 through 2020. The main independent variable of interest is *Unexercised Investment Opportunities (Peers)*, which is equal to the number of real options held by a firm’s peers and located within 3 miles of the section of interest. Data on horizontal wells are from DrillingInfo, while data for the remaining covariates are taken from Bloomberg, St. Louis Federal Reserve Bank, and publicly available firm reports. All variables are defined in Appendix Table A1 in the main paper. Robust standard errors, clustered at the *firm* level, are reported in parentheses. \*, \*\*, and \*\*\* denote significance at the 10%, 5%, and 1% level, respectively.

	Hazard Model for Project Exercise					
	(1)		(2)		(3)	
	Estimates	HI(%)	Estimates	HI(%)	Estimates	HI(%)
Unexercised Investment Opportunities (Peers) $_{j,t}$	-0.030*** (0.008)	-2.93	-0.037*** (0.008)	-3.65	-0.037*** (0.008)	-3.62
Cumulative Number of Well’s Drilled $_{j,t}$	0.053*** (0.004)	5.41	0.048*** (0.003)	4.95	0.050*** (0.003)	5.18
Unexercised Investment Opportunities (Own) $_{j,t}$	-0.035*** (0.010)	-3.47	-0.043*** (0.010)	-4.23	-0.051*** (0.010)	-4.99
Portfolio Concentration $_{i,t}$	0.188 (0.155)	20.72	0.096 (0.166)	10.06	0.076 (0.154)	7.94
Mean Distance Between Options $_{i,t}$	-0.059 (0.044)	-5.75	-0.067 (0.044)	-6.46	-0.074* (0.044)	-7.17
Firm Skill Level $_{i,t}$	-0.032 (0.056)	-3.14	-0.237** (0.103)	-21.06	-0.192* (0.104)	-17.48
Royalty Rate $_{j,t}$ (%)	0.685 (0.696)	98.36	0.663 (0.709)	94.07	0.582 (0.702)	79.01
Well Lateral Length $_{j,t}$ (1,000 ft.)			-0.047** (0.020)	-4.56	-0.012 (0.019)	-1.22
First Well’s Market Value $_{j,t}$			0.233*** (0.084)	26.21	0.207*** (0.078)	23.00
Peers’ Wells’ Value $_{j,t}$			0.063*** (0.012)	6.48	0.058*** (0.011)	5.97
Oil-to-Gas Ratio $_j$			0.308** (0.120)	36.03	0.340*** (0.122)	40.51
Drilling Cost $_{j,t}$			-0.019 (0.028)	-1.90	-0.039 (0.024)	-3.84
Futures Price $_t$					0.009*** (0.002)	0.90
Implied Volatility $_t$					-0.022*** (0.004)	-2.15
10-Year Risk Free Rate $_t$					0.176*** (0.052)	19.27
County Strata		Yes		Yes		Yes
<i>Pseudo – Loglikelihood</i>		-17,286		-17,174		-17,074
Wald Chi <sup>2</sup>		278		402		583
Observations		537,093		537,093		537,093



**Table IA.5: Robustness to the Reduced Sample with Data on Historical Landownership.** This table reports the results of Cox survival models in which the failure event is the drilling of a section's infill well (the exercise of the section's real option). The sample includes section-month observations over the period of 2005 through 2020 that have data on historical landownership from the Bureau of Land Management (BLM). The reduced sample includes 415,170 option-month observations covering 6,965 distinct options. The main independent variable of interest is *Unexercised Investment Opportunities (Peers)*, which is equal to the number of real options held by a firm's peers and located within 3 miles of the section of interest. Data on horizontal wells are from DrillingInfo, while data for the remaining covariates are taken from Bloomberg, St. Louis Federal Reserve Bank, and publicly available firm reports. All variables are defined in Appendix Table A1 in the main paper. Robust standard errors, clustered at the county level, are reported in parentheses. \*, \*\*, and \*\*\* denote significance at the 10%, 5%, and 1% level, respectively.

	Hazard Model for Project Exercise					
	(1)		(2)		(3)	
	Estimates	HI(%)	Estimates	HI(%)	Estimates	HI(%)
Unexercised Investment Opportunities (Peers) $_{j,t}$	-0.029** (0.013)	-2.86	-0.035** (0.014)	-3.42	-0.036*** (0.013)	-3.50
Cumulative Number of Well's Drilled $_{j,t}$	0.051*** (0.005)	5.22	0.046*** (0.005)	4.73	0.050*** (0.005)	5.11
Unexercised Investment Opportunities (Own) $_{j,t}$	-0.040*** (0.013)	-3.94	-0.046*** (0.013)	-4.49	-0.056*** (0.012)	-5.44
Portfolio Concentration $_{i,t}$	0.239 (0.212)	26.97	0.104 (0.207)	10.98	0.062 (0.188)	6.45
Mean Distance Between Options $_{i,t}$	-0.057 (0.044)	-5.56	-0.073* (0.041)	-7.01	-0.085** (0.039)	-8.18
Firm Skill Level $_{i,t}$	0.015 (0.067)	1.54	-0.180* (0.105)	-16.48	-0.130 (0.107)	-12.16
Royalty Rate $_{j,t}$ (%)	0.835 (0.739)	130.47	0.821 (0.693)	127.38	0.723 (0.703)	105.96
Well Lateral Length $_{j,t}$ (1,000 ft.)			-0.067** (0.027)	-6.49	-0.020 (0.026)	-1.97
First Well's Market Value $_{j,t}$			0.255*** (0.085)	28.99	0.227*** (0.076)	25.43
Peers' Wells' Value $_{j,t}$			0.057*** (0.017)	5.91	0.053*** (0.016)	5.49
Oil-to-Gas Ratio $_j$			0.308** (0.143)	36.08	0.347*** (0.134)	41.53
Drilling Cost $_{j,t}$			0.019 (0.034)	1.90	-0.026 (0.027)	-2.61
Futures Price $_t$					0.012*** (0.003)	1.23
Implied Volatility $_t$					-0.015** (0.007)	-1.49
10-Year Risk Free Rate $_t$					0.160** (0.069)	17.40
County Strata		Yes		Yes		Yes
<i>Pseudo – Loglikelihood</i>		-13,647		-13,556		-13,472
Wald Chi <sup>2</sup>		256		345		811
Observations		414,176		414,176		414,176

**Table IA.6: Landownership Fragmentation Through Time.** This table reports the results of linear regression models that investigate the validity of our instrumental variable. The sample includes township observations for which we have data on both historical and contemporaneous landowners. The dependent variable is the number of contemporaneous landowners in which firms contracted with during lease negotiations. The independent variable of interest is *Historical Landowners*, which measures the number of original landowners allocated parcels in the late 1800s and early 1900s. Data on oil and gas leases are from Drilling-Info, and data on historical landownership are from the Bureau of Land Management (BLM). All variables are defined in Appendix Table A1 in the main paper. Robust standard errors, clustered at the county level, are reported in parentheses. \*, \*\*, and \*\*\* denote significance at the 10%, 5%, and 1% level, respectively.

Dependent variable =	Contemporaneous Landowners	
	(1)	(2)
Historical Landowners	2.299*** (0.301)	0.875** (0.394)
County FE	No	Yes
Observations	2,024	2,011
$R^2$	0.11	0.45

**Table IA.7: Alternative Two-Stage Instrumental Variables Cox Model Specification.** This table reports the second-stage results of two-stage Cox survival models in which the failure event is the drilling of a section’s infill well (the exercise of the section’s real option). Model (1) displays the results using the 1<sup>st</sup> through 99<sup>th</sup> percentiles of the distribution for historical landowners. The sample includes section-month observations over the period of 2005 through 2020. The main independent variable of interest is *Instrumented Unexercised Investment Opportunities (Peers)*, which is equal to the instrumented number of real options held by a firm’s peers and located within 3 miles of the section of interest. We use the number of historical landowners within 3 miles of where the option is ultimately located to instrument for the number of peer options. Data on horizontal wells are from DrillingInfo, while data for the remaining covariates are taken from Bloomberg, St. Louis Federal Reserve Bank, and publicly available firm reports. Data on historical landownership used in the first-stage regressions are from the Bureau of Land Management (BLM). All variables are defined in Appendix Table A1 in the main paper. Robust standard errors, clustered at the *firm* level, are reported in parentheses. \*, \*\*, and \*\*\* denote significance at the 10%, 5%, and 1% level, respectively.

	Hazard Model for Project Exercise	
	(1)	
	Estimates	HI(%)
Instrumented Unexercised Investment Opportunities (Peers) <sub><i>j,t</i></sub>	-0.273** (0.112)	-23.88
Cumulative Number of Well’s Drilled <sub><i>j,t</i></sub>	0.091*** (0.023)	9.55
Unexercised Investment Opportunities (Own) <sub><i>j,t</i></sub>	-0.139*** (0.043)	-12.96
Portfolio Concentration <sub><i>i,t</i></sub>	-0.285 (0.218)	-24.81
Mean Distance Between Options <sub><i>i,t</i></sub>	-0.190*** (0.054)	-17.29
Firm Skill Level <sub><i>i,t</i></sub>	-0.125 (0.120)	-11.77
Royalty Rate <sub><i>j,t</i></sub> (%)	0.956 (1.027)	160.21
First Well’s Market Value <sub><i>j,t</i></sub>	0.211*** (0.072)	23.49
Peers’ Wells’ Value <sub><i>j,t</i></sub>	0.084*** (0.021)	8.74
Oil-to-Gas Ratio <sub><i>j</i></sub>	0.345*** (0.134)	41.17
Drilling Cost <sub><i>j,t</i></sub>	-0.045 (0.033)	-4.43
Futures Price <sub><i>t</i></sub>	0.016*** (0.003)	1.59
Implied Volatility <sub><i>t</i></sub>	-0.016* (0.008)	-1.56
10-Year Risk Free Rate <sub><i>t</i></sub>	0.116 (0.076)	12.35
County Strata		Yes
<i>Pseudo – Loglikelihood</i>		-13,167
Wald Chi <sup>2</sup>		224
Observations		400,740