Waiting on a Friend: Strategic Learning and Corporate Investment*

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Abstract

Using detailed project-level data, we document a novel mechanism through which information externalities distort investment. Firms *anticipate* information spillover from peers' investment decisions and delay project exercise to learn from their peers' outcomes. To establish a causal interpretation of our results, we exploit local exogenous variation from the 1800s that shapes the number of peers that a firm can learn from today. The incentive to wait is most salient for projects with uncertain profitability, when peers' underlying assets are similar, and in environments where peers are skilled. Finally, our results suggest that the anticipation of peer information dampens aggregate investment.

JEL classification: G30, G31, G41, D25, D82, D83, O13, Q15, R14

Keywords: Real options, strategic interactions, learning, peer behavior, investment, historical data

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1 Introduction

Corporate decisions convey information. Building a plant, divesting from an industry, entering a new market, or paying dividends makes public portions of a firm's private information set. In turn, firms' peers can learn from this revelation and adjust their behavior. This type of information spillover is well known to impact firms' investment decisions, corporate innovation, and financial policies (e.g., Conley and Udry, 2010; Leary and Roberts, 2014; Grennan, 2019; Bustamante and Frésard, 2020; Décaire et al., 2020).

It is unclear, however, whether or how pure information spillovers affect firms' decisions even *before* the information is revealed. Our paper investigates this question empirically. On the theoretical side, Chamley and Gale (1994) introduce a novel framework detailing such a dynamic for firms' investment policies. Two features of their work constitute the backbone of our study.[1] First, a firm's incentive to delay its own investment grows with the amount of information expected to be released by its peers. This arises from a firm's desire to take advantage of the private information revealed by the decisions and outcomes of its peers and make better informed investments. Second, the quantity of information expected to be released is increasing in the number of peers' real options that a firm expects to learn from upon their exercise. Together, these results facilitate an exact mapping from their model to our empirical specification, creating a tight link between the theory and the empirics.

To the best of our knowledge, our paper is the first to provide evidence on how firms adjust the timing of corporate investment when *anticipating* information spillover from peers. Consistent with Chamley and Gale's (1994) main prediction, firms delay investment decisions when they expect a greater amount of information to eventually be released. In particular, a one-standard deviation increase in the number of nearby peer options reduces the likelihood of project exercise by 13 percent at any given point in time. Our back-of-the-envelop calculation suggests that the corresponding delay for the average project costs firms 8% in

[1] In Section 2, we describe the model and expand our discussion of these two features.

pure time-value-of-money terms, compared with only a 0.34% expected increase in exercise value due to waiting. Such a discrepancy in the observed costs versus benefits suggests the unobserved benefits to waiting, like a reduction in uncertainty, may be large. We also find results consistent with a supplementary prediction in Chamley and Gale (1994), mainly, additional peer real options have a diminishing marginal impact on the firm's incentives to pull back investment. Moreover, in the cross-section, we show that the intensity of a firm's strategic behavior is stronger when (a) its project's expected profitability is uncertain, (b) its peers are more skilled, and (c) its peers' projects are more similar.

Finally, we document that these micro-level informational externalities significantly impact investment in the aggregate. In particular, a one-standard-deviation decrease in the concentration of firms holding options at the regional level decreases the total number of options exercised over our sample period by 19%. Taken together, our results highlight the importance of strategic interactions between firms even before decisions are made.

Ultimately, our paper can be interpreted through the lens of information disclosure, and thus, has implications for optimal disclosure regulations. In particular, our results suggest that an increase in the required quantity of investment-related information firms must disclose can have unforeseen adverse effects on firm investment behavior and aggregate industry dynamics.[2] To be sure, the impact of such regulations on investment will differ based on the nature of the industry and the characteristics of firms. For example, the disclosure requirements for firms regarding operating and geographic segments, products and services, and major customers in SFAS 131 are likely to depress investment more in industries facing greater uncertainty regarding project success, such as other energy firms (e.g. coal and metal mining) and discretionary consumer retail (e.g., restaurants and leisure) among others.

[2]Numerous regulations over the past three decades have increased reporting standards for public firms. For example, the Sarbanes-Oxley (SOX) Act in 2002 enhanced reporting for financial, including off-balance sheet, transactions. Further SOX requires an Internal Controls Report that verifies that accuracy of financial data. Such disclosure requirements may increase the amount, and quality, of investment-related information firms expect to be released by their peers. Other large changes include Dodd-Frank Act in 2010 and Financial Accounting Standards Board's (FASB) Statement of Financial Accounting Standards No.131 (SFAS 131) in 1997.

The findings in this paper represent a significant departure from the literature's current focus on information disclosure, strategic interactions, and social learning in the corporate setting. Part of this narrow focus stems from various empirical challenges and data limitations. First, few empirical settings are conducive to observing precise beginning and ending (exercise) dates for real options, for either a firm or its peers. Second, as supported by theory and empirical evidence (e.g., Dixit and Pindyck, 1994; Kellogg, 2014; Covert, 2015), it is essential to observe project cost, cash flow, and other associated factors to properly characterize the incentives for exercising real options. Third, it is rarely possible to distinguish between the effect of pure information spillovers and other strategic motives, such as the first-mover advantage, that relate to competition among firms. Finally, it is challenging to disentangle the effect of the number of available real options (from which a firm can learn) from the underlying asset quality. On one hand, a large number of peers acquiring options adjacent to a firm's assets may be positively associated with the underlying asset quality. On the other hand, large sets of unexercised options in a project's vicinity might be negatively correlated with the expected value of the project. Indeed, if peer firms acquire private information indicating that their project has limited potential, they may find it optimal to delay the option or forgo exercising it altogether. In this sense, the absence of firm investment also conveys information about the underlying asset quality (Giglio and Shue, 2014; Jin et al., 2021). Ultimately, these competing explanations are likely to confound any non-causal analysis.

In this paper, we exploit detailed project-level data on horizontal shale oil and gas infill wells located in Oklahoma and Louisiana during the period of 2005 to 2020. As described in Section 3.2, an infill well is the second well drilled on a leased section of land.[3] In total, we study firms' investment behavior following 8,770 distinct real options over 540,765 option-month observations. This setting offers four significant advantages in making progress on each of the key challenges in studying strategic learning and corporate investment.

[3] A section, is a standard unit of land measurement in the American Public Land Survey System, that corresponds to a 1 miles by 1 miles square of land.

First, the unique institutional features in these two states allow us to clearly identify the exact location of a firm's real options and to observe when each becomes available and is exercised. The richness of this environment also facilitates the investigation of various economic channels through which the strategic learning of peers affects corporate investment.

Second, the type of projects included in our analysis—oil and gas wells—all share a simple production technology and are exposed to the same natural resources. Further, existing regulations make it possible to observe each project's production level as well as other key characteristics. This enables us to obtain a reasonable measure of a project's economic potential while facilitating the comparison across projects.

Third, our analysis focuses on infill wells, which are wells drilled after the mineral rights have been acquired from the landowners and an initial well has been drilled. While the wait-and-see motive that we study exists in almost all industries, few empirical environments allow for a clean identification of its distinct effect.[4] For infill projects, the drilling decisions of one firm have no material consequences on the underlying value of its surrounding peers' options, other than through the private information that is disclosed. That is, there is no common pool problem as discussed in Kellogg (2014). Further, there is little in the way of a first-mover advantage. Effectively, each firm behaves like a monopolist on its plot of land. Ultimately, these features separate infill wells from many types of investments in which these competitive forces are not muted (e.g., entering a new product market). However, this setting enables us to cleanly disentangle the impact of pure information spillovers. Finally, with maturities over twenty years, infill wells are long-dated real options, which are necessary to properly study exercise incentives.

Finally, we exploit the features of our setting to combine three empirical strategies to properly control for underlying asset quality and to obtain exogenous variation in the number of peers with real options in a well's vicinity. First, in all of our main analyses, we include controls for the quality of the wells previously drilled by the firm and its peers in the region.

[4]For example, automakers can learn from the outcomes of their peers when deciding to adopt new technologies or enter new geographic markets.

Second, we control for time-invariant geographic characteristics associated with the region in which the option is located. Each of these strategies is meant to capture variation in the underlying asset quality that may simultaneously impact drilling decisions and the number of peer options. Third, we introduce a novel instrumental variable that uses arbitrary variation in historical landownership fragmentation in the region surrounding a firm's option.

Specifically, our instrument measures the number of original landowners within three miles of where a firm ultimately establishes a real option. That is, we exploit Bureau of Land Management (BLM) data on parcels deeded to settlers through multiple land grant programs enacted throughout the 1800s and early 1900s. To validate our instrument, we present evidence showing that landownership fragmentation is persistent over time, as the historical measure explains 45% of the contemporaneous landownership fragmentation within a county.[5] Intuitively, smaller values of landownership fragmentation indicate that a firm can collect the drilling rights to most of its surrounding sections relatively easily, for example, by communicating and coordinating with a few individual landowners today. Conversely, larger values suggest that a firm must approach numerous landowners to lease the drilling rights for an otherwise similar group of sections, significantly raising the present-day coordination costs (Leonard and Parker, 2021). Because these coordination costs affect the ability of a firm to successfully collect the drilling rights of all neighboring sections before its peers acquire any, it impacts the share of local private information held by the firm versus that held collectively by its peers.[6]

This strategy strongly captures the dynamic between coordination costs for the firm and the number of available options held by any of the firm's peers in a region, as F-statistics are over 10 in all specifications (Staiger and Stock, 1997; Stock and Yogo, 2005). This is true even after conditioning on the number of wells already drilled by firms in the same region. Overall, this evidence suggests our instrument meets the relevance criterion.

[5] Similarly, the measures exhibit a high level of correlation, 33%.

[6] Once firms acquire the leasing right to a section, they can conduct seismic surveys, which improves the quantity of private information they possess for that location.

Moreover, most of the land grants were assigned to settlers before 1910 (89% of the BLM observations) and started as early as 1821. This period not only significantly precedes the fracking revolution that occurred in the 2000s , but it also took place before the first oil and gas revolution that started in the early part of the 20^{th} century for the two states included in our study (see Figure 1 and 2; Blum, 2019). Four federal programs accounted for the majority of the grants: (a) the Homestead Act (42%) allocated land to American citizens willing to settle and populate the land, (b) the Indian Allotment Act (11%) parceled out reservation lands across its members, (c) the Script Warrant Acts (4%) rewarded soldiers for their efforts, and (d) cash-entry programs simply sold land titles to prospective settlers willing to farm the region (39%)[7]. This suggests that the main motive driving the allocation of subsurface rights to landowners was not driven by the oil and gas potential of the land, but rather it was guided by the political will to populate the American Western Territories. Finally, to further alleviate any remaining concerns regarding a link between our instrumental variable and the options' underlying asset potential, we document that the historical landownership fragmentation has no relation with the quality of the wells.

Using a linear first-stage regression and a Cox hazard model in the second stage, we find a strong and persistent negative relationship between the number of available peer real options and the likelihood that a firm drills a new infill well in the region. These results suggest that the anticipation of information revelation has a causal impact on firm investment policy.

A rich literature explores how different types of information disclosure can impact economic activity. First and foremost, disclosure and regulatory compliance is costly, which has implications for the mix of public and private firms (Ewens et al., 2021). Our paper highlights a potentially overlooked regulatory cost: reduced investment due to the anticipation of information spillover. Second, Banerjee et al. (2018), Gao and Liang (2013), and Goldstein and Yang (2019) provide intuition on when certain types of information disclosure

[7]None of the land grant programs in the BLM sample include the *Stock-Raising Homestead Act*. This distinction is key, as that particular program did not grant settlers with both the land and mineral rights, leading to a *split-estate* situation. In contrast, the four program discussed above transferred all of the ownership rights to settlers.

can attenuate price informativeness. Further, Edmans et al. (2016), Han et al. (2016), and Goldstein and Yang (2019) find that information disclosure can even negatively impact real economic outcomes.[8] We contribute to this literature by documenting that large quantities of expected information spillover have the potential to generate related disincentives for corporate investment.

We also contribute to several additional strands of literature. First, we add to an evolving understanding of how firms set investment policies within a real-options framework (Grenadier, 1996, 1999, 2002; Grenadier and Wang, 2005; Novy-Marx, 2007; Grenadier and Malenko, 2011; Kellogg, 2014). Second, our paper contributes to a growing literature on peer effects, strategic interactions, and firm policies (Leary and Roberts, 2014; Foucault and Frésard, 2014; Grennan, 2019; Décaire et al., 2020; Bustamante and Frésard, 2020).

Our paper is most closely related to Décaire et al. (2020), who document that the timing of a firm's options exercise is strongly influenced by its peers' exercise behavior, consistent with an information revelation channel (Grenadier, 1999). However, whereas Décaire et al. (2020) find that firms speed up investment after positive private information is revealed by peers' actions, we document that the anticipation of private information being released through their peers' investment decisions delays firms' corporate investment. Combined, these two results reflect Chamley and Gale' (1994) equilibrium in a complementary way: periods of sluggish investment due to strategic learning incentives among peers are followed by intense investment cascades. The delay imposed by the anticipation of information spillover is similar to those caused by uncertainty (Dixit and Pindyck, 1994; Ingersoll Jr and Ross, 1992), and frictions such as financial constraints (Whited, 2006) and debt overhang (Wittry, 2021).

The paper is organized as follows. Section 2 presents a brief overview of the underlying theory motivating our paper. Section 3 explains important institutional features of our setting. Section 4 describes the data and methodology used in our analysis. Section 5 presents

[8] Our study is also related to a large literature—particularly in accounting—on mandatory and voluntary financial disclosure and their impact on corporate investment. For example, see Shroff et al. (2014), Kraft et al. (2018), Ferracuti and Stubben (2019), Cho and Muslu (2021), and Breuer (2021). Roychowdhury et al. (2019) provide a review of this literature.

our main results and several extensions based on theoretical works and empirical insights. Section 6 reports on tests that account for likely omitted variables bias. Section 7 examines the impact on aggregate levels of investment. Section 8 examines several additional empirical specifications that probe that robustness of our main results, and Section 9 concludes.

2 Model of Investment Delay and Information Spillover

Chamley and Gale (1994) model firms' investment decisions as a multiplayer game in which each firm, with some positive probability, is endowed with a profitable, yet risky investment opportunity (real option). Though the returns to exercising this option are not certain, they are positively correlated with each firm's private information. This private information becomes publicly available only when a firm makes the investment. Because the model is one of pure informational externalities, there are no other meaningful competitive forces, such as first-mover advantage. Then, in equilibrium, firms delay exercising their options as they wait to observe peers' decisions.

The authors are careful, however, to note that there are actually two potential (non-mutually exclusive) motives that may explain why firms delay their investment decisions. First, it is possible that firms simply expect that their investment will be unprofitable. That is, the expected value of extracting the underlying asset is below the threshold and firms delay the investment decision until they can confirm that it is profitable in expectation. Second, firms have pure learning incentives and find it valuable to wait an additional period prior to exercising. The benefit in such a delay stems from the quantity of information expected to be released in the following period. Thus if delaying investment and learning from their peers sufficiently updates their priors as compared to the current period's valuation, waiting is NPV positive. In Chamley and Gale's (1994) notation, we can express this as

$$\delta W(\xi, h) > v(h) > 0; \text{ Proposition 4.} \tag{1}$$

where δ is the firm's discount rate, ξ is the amount of information expected to be released next period, and h is the number of peer investment decisions that have already been made. Then, $W(\xi,h)$ denotes the undiscounted investment value after waiting an additional period for a given pair (ξ,h), and *v(h)* is the expected investment profitability this period conditional upon only the exercise of h peer real options. The authors further assume that the value-to-wait ($W(\xi,h)$) increases in the expected amount of information to be released next period (ξ).[9] In sum, Proposition 4 implies that there exists an equilibrium in which the amount of information expected to be released next period is sufficiently high that some firms find it valuable to delay investment decisions, even when investment is already expected to be profitable in the current period.

Providing further structure for our empirical work, Chamley and Gale's (1994) Lemma 2 shows that the expected quantity of information to be released in a period (i.e., ξ) is positively related to the number of peer options. Intuitively, in our setting, the more peers' options surrounding a firm's option in a given period, the greater the number of options the firm expects to be exercised *next* period in each state of the world with respect to the underlying asset quality. Combined, these results allow us to directly map our empirical analysis into Chamley and Gale's (1994) theoretical framework.

3 Institutional Details

This sections explains important features and advantages of our institutional setting. In particular, we focus on horizontal infill oil and gas wells located in Oklahoma and Louisiana in order to solve two key challenges that have hindered researchers: clearly characterizing the details of investment opportunities and sharply identifying peers.

[9] This assumption is consistent with a positive bias in our empirics, which we discuss in Section 6. That is, the value of the underlying asset is positively correlated with the number of peer options.

3.1 Land Use Details

Shale resources, or plays, are located in nearly thirty states across the U.S (e.g., see Figure 3). We focus our analysis on Oklahoma and Louisiana, however, for several reasons. First, Oklahoma and Louisiana are behind only Texas and Pennsylvania in annual natural gas production (Kopalek et al., 2019). Thus, these two states represent a significant portion of the total horizontal oil and gas wells in the country.

More importantly, however, two institutional land features in Oklahoma and Louisiana make these states particularly suitable for our analysis. First, the land survey method used in both of these states is the rectangular survey system.[10] Figure 4 depicts the difference between the rectangular survey system used Louisiana and that of Texas, which was originally deeded with Spanish land grants. In particular, the rectangular survey method creates standardized land units called sections that each measure 1 mile by 1 mile (640 acres), as opposed to the patchwork of irregular land lots in states such as Texas. Importantly, this provides us with a well-defined land unit in the analysis.

Second, both Oklahoma and Louisiana have simple and well-defined spacing requirements for horizontal well drilling (i.e., the minimum amount of acres to be acquired by a firm in order to drill a well). Conveniently, oil and gas firms operating in Louisiana and Oklahoma acquire the leasing rights to an entire section to satisfy the regulatory spacing requirement for horizontal wells in these two states. In contrast, such standards are much less prevalent in other states. This lack of structure makes it difficult to cleanly associate a real option with a specific well. Combined, these institutional features make it particularly advantageous to study real option exercise in Louisiana and Oklahoma.

[10] This survey method, also called the Public Land Survey System, was created by the Land Ordinance of 1785.

3.2 Horizontal Infill Wells

Aside from concentrating on specific states, we also focus on a particular type of corporate investment project—horizontal *infill* oil and gas wells—a strategy first introduced by Kellogg (2014) and Décaire et al. (2020). Infill wells in Oklahoma and Louisiana are nearly identical, as horizontal drilling proceeds similarly in both states. First, firms secure the drilling rights for a section by contracting with the local landowners. These initial drilling leases typically expire after three years if the firm has not drilled at least one well on the section. However if a well is drilled during the contract term, the section becomes "held-by-production." This grants the firm with an option to further develop the section with additional "infill" wells, so long as the first well remains in production. Figure 5 provides a graphical example of a township that includes a section with no wells, a section that is held-by-production, as well as a section with a drilled infill well (a section in which the option has been exercised). Such a strategy of focusing on infill wells offers several benefits in the context of studying real options exercise and pure information spillovers.

First, because of the nature of infill wells, along with the specific features of the states we analyze, we are able to circumvent the most challenging data limitation in studying real options—simply observing when a firm holds a real option. In particular, we are able to measure exactly when the real option becomes available to the firm as it corresponds to the date a section's initial well is drilled. Likewise, we can observe the precise date each option is exercised (the date the first infill well is drilled), or if option goes unexercised over the course of our sample. Moreover, due to the rectangular survey method and minimum spacing requirements, there is no confusion about whether a newly drilled well is an infill well. That is, we are able to precisely define newly drilled wells as either the start of a new option, or the exercise of an existing option, simply by observing the section in which it is drilled.

Second, pure learning incentive are generally difficult to disentangle from other competitive strategic actions, such as first move advantage. However, in the context of our analysis, firms have monopoly power over their section, meaning that no other firm can attempt to drill on the lot before they do. At the same time, because shale resources are trapped between tightly packed sheets of rock, the extraction zone of horizontal wells is highly localized. Combined with spacing regulations (i.e., set of rules preventing firms from drilling too close from each others) horizontal wells are unlikely to face a common pool problem generally leading to a tragedy of the commons. These features allow us to rule out other confounding explanations (first-mover advantage) and cleanly identify the impact of pure information spillover.

Finally, infill wells tend to be long-maturity options. Without sufficient maturity (e.g., short-dated options such as initial drilling decisions to hold by production), it is difficult to disentangle the different factors that predict exercise, as firms tend to systematically trigger these options quickly before they expire (Herrnstadt et al., 2020). Because lease contracts stipulate that firms can drill infill wells so long as the initial well is producing, the expected maturity of each real option in our setting corresponds to the expected productive life of a horizontal well, which ranges between 20 to 40 years (see, e.g., Blum, 2019). Figure 6 shows the average well production function over its life for our sample, which starts in 2005. Although we cannot validate if the wells in our sample will have a production period longer than 15 years, over 70 percent of the wells drilled in 2005 were still producing in 2020, providing additional support for the long life expectancy of a well.

3.3 Identifying Peer Firms

Beyond the difficulties associated with observing real options, studying strategic interactions and learning incentives presents a second challenge. That is, precisely identifying peers in a corporate setting is empirically difficult. Prior literature has proposed methods based on industry (e.g., Leary and Roberts, 2014, Grennan, 2019), and product similarity (Foucault and Frésard, 2014; Hoberg and Phillips, 2016). Each of these measures of peer influence has strengths and weakness. For example, identifying peers based on industry classifications such as NAICS or SIC codes is simple, yet crude, as such broad strokes cannot separate between competitors or firms within the same supply chain.

Again, the organic features of our setting provide two significant advantages. First, all of the firms in our sample are active in the same industry: oil and gas exploration and production. Second, the projects we analyze are rather homogenous in their characteristics; they share the same technology of horizontal drilling and produce the same resources, oil and gas. This allows us to more cleanly identify comparable projects held by a firm's peers without the need to rely on noisy proxies usually employed in the literature.

Ultimately, our strategy exploits the relative homogeneity amongst the projects and firms in our sample, along with the benefits of land policy and infill wells in Oklahoma and Louisiana to define our main variable of interest: the number of real options held by a firm's peers. Specifically, *Unexercised Investment Opportunities (Peers)* equals the number of "held-by-production" sections owned by different operators located within 3 miles of a firm's own option.[11] That is, we concentrate on sections owned by peers with with an initial drilled well, but no drilled infill wells. Figure 7 provides a visual of this construction for the real option highlighted in the red square.

4 Data and Methodology

Our main dataset, which was provided by DrillingInfo, covers all horizontal wells drilled in both Oklahoma and Louisiana between 2005 and 2020 (see Figure 2). This dataset includes each well's drilling start date, along with a set of project characteristics such as the well's GPS location, and lateral length. Our final data panel consists of section-month observations, where a section enters the sample when the option to infill a well becomes available and remains in the sample until an infill well is drilled, or our sample ends. In total, we analyze 530,566 section-month observations covering a total of 8,662 unique options and 436 distinct

[11]This distance, when branching in all directions, mimics the size of a township; however, as discussed in Section 8 below, our results are not sensitive to this particular choice.

firms. Overall, 39.9 percent of the options are exercised during the sample period.

We augment these data points with four additional data sources. First, we use hand-collected measures of per-project capital expenditures (which includes per-horizontal-foot drilling costs) and estimated operational costs obtained from public filings and regulatory documents, as in Décaire et al. (2020). We use this data to obtain time-varying estimates of the cost to drill an infill well in each month, based on the horizontal length and per-foot drilling cost of the first well drilled on that section. Second, we add monthly financial market data, such as the eighteen-month crude oil futures prices and implied volatility from Bloomberg, and the ten-year risk-free rate obtained from the Federal Reserve Bank of Saint Louis. The eighteen-month futures contract is well-suited for our analysis because a horizontal well's half-life (the amount of time it takes to receive half of the well's production) is equivalent to that horizon. Moreover, Kellogg (2014) shows that implied volatility best captures forward-looking uncertainty.

The final two sources consist of data on landownership. The first is from the Bureau of Land Management and contains information on original property rights allocated to settlers via federal programs in the 1800s and 1900s.[12] We use this data to construct our instrumental variable. The second source contains oil and gas lease data, provided by DrillingInfo, which contains information on contemporaneous landownership. Unfortunately, this data only include landownership fragmentation for sections that are ultimately leased by oil and gas firms, limiting its use in our main instrumental variable strategy. However, it does facilitate a reasonable, though admittedly ad hoc, test exploring whether historical landownership fragmentation patterns have explanatory power over contemporaneous landownership fragmentation.

Table 1 presents summary statistics for the data used in our main regressions. In particular, Table 1 suggests that for each of the options a firm owns, there are 4 of its peers' unexercised options, and 5 of its own unexercised options located in the surrounding region,

[12] It is possible to access the BLM data using this link https://glorecords.blm.gov/BulkData/default.aspx.

on average. Moreover, the average firm in our sample owns 19 options through the sample and exercises one per year. Additionally, Table 1 displays the summary statistics for both firm- and well-level covariates, as well as, financial market variables for the oil and gas industry.

Similar to studies such as Leary and Roberts (2005), Whited (2006), and Wittry (2021), we employ a Cox proportional-hazards rate model to capture our dynamic of interest. This type of model provides a natural way to explore how strategic learning incentives among peers affect the timing of exercising real options.. Specifically, for a random duration of time T, we can cast the hazard function of our problem such that

$$h(t) = \lim_{m \to 0} \frac{\Pr(t \leq T < t + m | T \geq t)}{m} \tag{2}$$

In this equation, $h(t)$ denotes the instantaneous rate at which a firm is likely to exercise its real option conditional on not having exercised it at time t. Put differently, we can interpret $h(t)$ as the probability that a firm will exercise its real option during the next period m, conditional on not having exercised it up to time t. In the context of our analysis, this duration model allows us to measure the effect of strategic learning incentives among peers between the time a real option becomes available and the time it is exercised.

5 Main Results

We start our analysis by considering the impact of peer options on the timing of investment decisions in a general way. We separate firms' investment opportunities for which there are no peer options in the same vicinity for the entire life of the option in question from those that have at least one nearby peer real option at any point in the option's life. Figure 8 plots the Kaplan-Meier survival function for each of these groups of projects. This empirical specification offers a number of advantages. First, the survival functions represent an intuitive visual of exercise likelihood over time. Second, the comparison of survival probabilities provides an initial nonparametric estimate of firms' incentive to wait when they have the potential to learn from their peers.

Consistent with theory (e.g., Chamley and Gale, 1994), Figure 8 displays a stark difference in survival probability between the two subsamples. Further, the 95% confidence intervals do not overlap, indicating that at all points in event time, the probability of exercise for projects in an environment with peer real options is statistically different than that of projects with no peers. This suggests that the anticipation of private information release through peers' option exercise significantly impacts the timing of firms' investment decisions.

Moreover, the delay induced by potential information spillover can be quite large. For example, the difference in implied survival for projects in the 25th percentile of each respective group is 14 months. From a pure time-value-of-money perspective, waiting an additional 14 months before drilling costs the firm 8% of a project's net present value, or \$177,530 for the average project.[13] In our sample, this cost appears to exceed any observed benefits of waiting. That is, Internet Appendix Table IA.1 Model (2) suggests that each additional month an option is held before exercising is associated with an increase of at most 0.024% in project value when the infill well is ultimately drilled. Thus, a 14-month delay corresponds to only a 0.34% NPV increase (\$7,552) relative to the sample mean. On one hand, the discrepancy in the observed costs and benefits of waiting suggests that the unobserved benefits of delaying investment decisions, such as reduced uncertainty and forgoing poor projects, could be large. For example, if we assume firms are optimizing efficiently, the "shadow" benefits of waiting could be as large as 7.7%, or nearly \$170,000 on the average project. On the other hand, it may be the case that the total benefits of delay are indeed small, thus making the effect we document a true distortion.

[13] Given the average NPV of a well is \$2,203,260 and the sample average discount rate is $R_{CAPM} = 7.48\%$, the value loss is equal to $\left[1 - \left(\frac{1}{1+R_{CAPM}}\right)^{\frac{14}{12}}\right] \times NPV = 8.06\% \times$ \$2,203,260 = \$177,530. See Appendix B, for more details about the calculation of these metrics.

5.1 Baseline Multivariate Hazard Model Results

To refine and deepen our analysis, the remainder of the paper focuses on multivariate Cox hazard regression models with a continuous measure of the potential available information spillover.[14] The Cox model is flexible enough to include a host of time-varying control variables that likely impact project exercise. Further, we use stratification at the county level to account for geographic time-invariant unobservable heterogeneity. For example, the quality of the underlying assets in a specific geographic region are likely to be highly correlated. Like fixed effects, the county strata remove the portion of an exercise decision that is attributable only to geographic location; however, they do so in the Cox setting without inducing incidental parameter bias (Allison, 2002).[15] Finally, because our treatment is geographically based, we cluster our standard errors at the county level (Abadie et al., 2017; Petersen, 2009).[16]

Table 2 reports the results of our baseline Cox hazard models. Our main independent variable of interest is *Unexercised Investment Opportunities (Peers)*, which measures the number of real options held by a firm's geographic peers. To facilitate the interpretation of the regression coefficients, we also report the hazard impact percentage, which equals $100 \times (HazardRatio - 1)$. This corresponds to the percentage change in exercise likelihood given a one-unit change in the variable of interest. The coefficient on *Unexercised Investment Opportunities (Peers)* in Model (1) is -0.030 and is statistically significant at the 1% level. The hazard impact percentage for this coefficient is -2.93%, which suggests that a one-standard deviation increase in the number of real options held by peers reduces project

[14] The continuous measure of available information spillover most closely matches the models in Chamley and Gale (1994) and Acemoglu et al. (2011). However, our results are not sensitive to this modeling decision. Section 8 discusses results that use an indicator variable equal to 1 for projects with any positive number of peer options. These results are contained in the Internet Appendix (Table IA.2) and are quantitatively and qualitatively similar to our main results below.

[15] Allison (2002) shows that incidental parameter bias from using fixed effects in Cox models is on the same order of magnitude as those in probit and logit models. However, he also argues that stratification on variables in a repeated-events setting, such as ours, yields unbiased estimators.

[16] Wells in the same county are likely to share similar characteristics and thus, face a similar probability of being exercised. Our inferences are not sensitive to this particular choice of cluster level. E.g., see Section 8.

exercise likelihood by 10.7%.

Model (1) also includes multiple control variables.[17] We start by including firm-level covariates that are likely to impact project exercise. For example, we include the total number of wells drilled in the vicinity. This should proxy for the time-varying drilling potential of the region. Further, we control for the additional investment opportunities the firm has in the same region, the firm's geographic dispersion as measured by the mean distance between its options, and finally, measures of the the firm's skill and its portfolio concentration.

Models (2) and (3) add additional covariates at the option and market level, respectively. In particular, in Model (2), we add standard inputs in real options models (Dixit and Pindyck, 1994), such as a proxy for the option's underlying asset quality (i.e., the market value of the first well dug in the section) and the estimated cost of drilling the well. Moreover, Model (2) includes the market value of a firm's peers' average wells to proxy for the signal of quality the firm receives, and finally, the first well's oil-to-gas ratio.

Model (3) adds the cost of equity (i.e., the oil and gas industry beta), the 10-year risk-free rate, the eighteen month futures price, and implied volatility of the underlying asset. Futures price and volatility of the underlying asset have often been used as proxies for the expected cash flow and cash flow risk of the project itself (Kellogg, 2014). The addition of these control variables significantly raises the bar for alternative mechanisms to be driving our main results. Each of these controls exhibit the expected sign and, with the exception of portfolio concentration, are statistically significant at least at the 5% level.

The coefficients on *Unexercised Investment Opportunities (Peers)* are larger in magnitude in Models (2) and (3). For example, in Model (3), the coefficient remains significant at the 1% level, but increases to -0.037. Given the hazard impact percentage of -3.66%, the economic magnitude is also significant. In particular, a one-standard deviation increase in real options held by a firm's peers reduces exercise likelihood by 13.4%. This indicates the anticipation

[17] All variables are defined in Appendix Table A1.

of information spillover is on the same order of magnitude in terms of importance as other drivers of real option exercise (see, e.g., Dixit and Pindyck, 1994; Kellogg, 2014).

Overall, the results in Table 2 are supportive of Chamley and Gale (1994). The remainder of this section considers several extensions to the baseline models, including a test of a supplementary prediction in Chamley and Gale (1994). Further, we explore several additional economic mechanisms that may be related to our main results.

5.2 The Diminishing Marginal Impact of Additional Peer Options

Chamley and Gale (1994) present several ancillary results that characterize their equilibrium. The nature of our setting is particularly conducive to assessing one of them: as the number of options grows, the rate of investment eventually becomes unresponsive to additional options. This finding is similar to the idea that additional peer real options have a diminishing impact on project exercise and is rather intuitive, as firms may be particularly willing to delay investment in anticipation of the information provided by the first or second peer option exercise. However, the incentives for waiting are likely to decay quickly as more peer options eventually saturate the learning environment.

We empirically test this prediction in two ways. First, we model the impact of the number of peer options as a quadratic function. That is, we include the square of the number of real options held by a firm's peers. Second, we relax our assumption regarding the specific functional form of the underlying relationship. In this alternative specification, we interact the number of unexercised options held by a firm's peers with an indicator variable equal to one if the number of peer options is less than the sample median (three options). This interaction is akin to testing for significant differences between the slopes of the unexercised investment opportunities held by a firm's peers below and above the sample median.

Table 3 displays the results. Panel A focuses on the quadratic function approach. The coefficients on the squared term are positive and statistically significant in both models. In addition, the coefficients on *Unexercised Investment Opportunities (Peers)* are both economically large, negative, and significant at the 1%. These results suggest a strong degree of concavity in the underlying relationship between a firm's investment decisions and the number of peer real options.

Panel B of Table 3 reports models that interact the number of peer real options with the indicator signifying this number of peer options is less than the sample median. In Model (2), the interaction terms is negative and significant, suggesting that the slope for below-median peer options and above-median peer options are significantly different from each other. Moreover, the hazard impact percentage for this term in Model (2) is -6.4%. This indicates that the impact of increasing peer options up until the sample median decreases project exercise likelihood by over 6 pp. *more* than increasing peer options above the sample median. Overall, both panels provide support for Chamley and Gale' (1994) secondary result.

5.3 Model Extensions

In Chamley and Gale (1994), options are ex-ante identical, and each peer reveals equal information when they exercise their options. In our setting, this would be analogous to each firm (a) learning only from the timing of its peers' investment decisions, not the outcomes, and (b) indiscriminately valuing peers and peer projects, regardless of their characteristics. Although this model yields precise predictions, it presents a stylized view of reality. Thus, to deepen our analysis and better capture strategic learning dynamics, we borrow from additional theoretical work and empirical insights and extend our results in three ways.

5.3.1 Signal Quality

First, Acemoglu et al. (2011) consider a similar *war-of-attrition* setting in which firms can learn from not only their peers' option exercise decisions, but also the quality of the outcomes. Their model predicts that when firms observe signals suggesting high underlying asset quality, their incentive to wait in anticipation of additional information weakens. In our setting, this is equivalent to firms internalizing both how many peers exercise their options, as well as the production value of their associated drilled wells.

To empirically investigate Acemoglu et al. (2011), we measure the signal of quality using the market value of the mean drilled well amongst a firm's peers. A high mean well value suggests that the underlying asset quality for the firm's wells is also likely high, and thus the incentives to wait and learn more are muted. Table 4 presents the results of interacting *Unexercised Investment Opportunities (Peers)* with *Peers' Wells' Mkt. Value* which is equal to the natural log of the mean well value amongst a firm's peers. The coefficient on this interaction term is significant at the 1% level in both models. Moreover, with a hazard impact percentage of 5.05% in Model (2), the economic magnitude is large. This suggests for a firm with the mean number of peer real options (3.9), a 1% increase in the mean market value of drilled peer wells increases project exercise likelihood by over 5%. Consistent with Acemoglu et al. (2011), this result indicates that firms' incentive to delay investment to learn from their peers is most salient when there is more uncertainty regarding the profitability of the potential investment.

5.3.2 Peer Quality

For the second extension, we explore how the quality or skill of a firm's peers interacts with their incentives to delay investment. Intuitively, firms may find the information produced by the actions of their peers with a successful track record more valuable, increasing their incentive to wait for such peer decisions. Consistent with this idea, Conley and Udry (2010) and Décaire et al. (2020) present empirical evidence that firms' decisions tend to be mainly influenced by their successful peers' actions.

To empirically investigate this prediction, we differentially analyze the influence of high-skill and low-skill peers. We measure a firm's skill through the quantity of oil or gas its average well produces. That is, we define a firm to be high-skill if its mean well produces more oil or gas than the median well in our sample, and low-skill otherwise. Next, to obtain the two skill-based measures of peer options, we proceed in a similar fashion as in our main specification. We count the number of wells in a firm's vicinity that are held by high-skill peers and low-skill peers separately and we scale each by its own standard deviation. Scaling the variables by their standard deviation allows us to readily compare the economic magnitude between the two estimated coefficients.

Table 5 displays the results. In both models, the coefficients on unexercised investment opportunities held by a firm's high-skill peers are large, negative, and significant at the 1% level. Standing in stark contrast, those on low-skill peers' options are small, positive, and indistinguishable from zero. Further, in testing for significant differences between the two sets of coefficients, we find the Chi^2 test statistics are 11.17 and 12.09 in Model (1) and Model (2), respectively. Each is significant at the 1%. Finally, the economic magnitude of the hazard impact percentage in Model (2) indicates that a one-standard-deviation change in high-skilled peers' unexercised investment opportunities reduces exercise likelihood by nearly 14%. Thus, the entire effect from our main result in Model (3) of Table 2 (HI% $\times$ SD = -13.4%) is concentrated in highly skilled firms.

5.3.3 Project Similarity

In a final extension, we assess the role of project similarity. Naturally, peer projects with a higher similarity likely contain more relevant information to the firm when exercised. In this sense, this extension is comparable to measuring the quantity of information content in a signal the firm receives, rather than the quality of the signal itself. As such, the incentives to wait to learn from project exercise are likely greater for more similar projects. This argument is consistent with Cho and Muslu (2021), who show that the content of peer MD&A reports influences firm investment, but only among peers with a high degree of product similarity (Hoberg and Phillips, 2016).

To empirically assess this hypothesis, we measure similarity through the precise resource mix (oil vs. gas) in the first year of production for a section's initial well. Even in our sample, which includes a degree of geographic concentration, the resource mix across wells is highly variable. In fact, the standard deviation of the oil-to-gas ratio is 34%. This variation suggests a degree of project heterogeneity, which can obviously impact learning incentives.

We start by creating indicator variables for projects that are majority oil (e.g., oil $>$ 50% of the total resource quantity) and those that are majority gas (gas $>$ 50% of the total resource quantity). We then count separately the number of wells in a firm's vicinity that are the same majority resource and those that are a different resource. As we did with the peer quality variables in the previous section, we scale each by its own standard deviation.

The results appear in Table 6. Peer options from both same-resource projects and different-resource projects negatively impact exercise decisions, however, the effect is much stronger for same-resource options. For example, in Model (2), the coefficient on *Unexercised Investment Opportunies (Same Resource)* is -0.140 and is significant at the 1% level, while that of *Unexercised Investment Opportunies (Different Resource)* is -0.035 and is insignificant at conventional levels. Furthermore, the coefficients are significantly different from each other (Chi^2 statistic = 15.49). Just as the results were concentrated in high-skill firms in Section 5.3.2, the bulk of our main effect is concentrated in peer options that have a similar resource mix. In all, these results once again point to the fact that firms do not indiscriminately wait on peer exercise, but rather wait for projects that are likely to be the most informative.

6 Omitted Variable and Instrumented Results

A potential concern with our analysis in Section 5 is that the number of options owned by peers in a region is not likely to be randomly assigned across projects. The most salient endogeneity issue is that the number of peers' real options may be correlated with the unobservable underlying asset value, that is, the quantity of the oil or gas in the ground. In this sense, our analysis is likely to suffer from an omitted variables bias (OVB).

To mitigate this concern, we introduce a novel instrumental variable based on historical landownership rights allocated to U.S. citizens through federal programs in the 1800s. Specifically, our instrument—*Historical Landownership Fragmentation*—measures the number of original landowners in the late 1800s and early 1900s that are located within three miles of where the options in our sample are ultimately established.

Prior empirical work has shown that historical landownership patterns strongly explain contemporaneous patterns (Curry-Roper, 1987). That is, within a given region, higher numbers of historical landowners implies a higher degree of fragmentation today, all else equal. We also verify this relationship in our data using the number of individual landowners a firm contracts with during mineral rights lease negotiations. Figure 9, Panel A shows that, after removing outliers, the correlation between historical and contemporaneous fragmentation at the township level is 33%. Furthermore, Internet Appendix Table IA.3 presents regressions that suggest the number of historical landowners can explain as much as 45% of the variation in contemporaneous landowners within a county.

Along with this strong relation through time, Figure 9, Panels B and C present the intuition behind the use of the historical fragmentation as our instrumental variable. The panels depict landownership in two distinct townships in Woodward County, Oklahoma as of 1910. Smaller values of historical landowners (depicted by Figure 9 Panel B) indicate that a firm is likely to be able to collect the drilling rights to multiple contiguous sections by approaching fewer individual landowners today. However, the more fragmented landownership was in the early 1900s (depicted by Figure 9 Panel C), the higher the coordination costs are likely to be today, making it harder for a single firm to acquire all the sections' leases before its competitors secure the rights to some.[18] Thus, higher values of the instrumental variable suggest a greater share of the surrounding options will be held by its peers.

[18] Investment delay is not a factor at the lease acquisition stage because the lease contracts generate negligible costs for the firm if the wells do not produce. For example, the typical lease contract stipulates an 18.75% of cashflow royalty payment to the landowner but only an immediate "signing bonus" payment of a few hundred dollars. Thus, firms have strong incentives to acquire the rights to as many sections as possible as fast as possible in hopes of some fraction of them ultimately producing.

Panel A of Table 7 presents the first stage of our instrumented regression and confirms this intuition. That is, when regressing *Unexercised Investment Opportunities (Peers)* on *Historical Landownership Fragmentation* we find a statistically significant and positive coefficient. In particular, a one-standard deviation increase in the number historical landowners is associated with a 12% increase in the number of peer options, relative to the sample mean. Further, in each model specification, the F-stats are above the critical threshold of 10 (Staiger and Stock, 1997; Stock and Yogo, 2005). This positive relation indicates that after controlling for the number of options the firm itself owns, regions with more fragmented historical landownership are associated with a greater proportion of the total available options held by the firm's peers.

The main identifying assumption in this strategy is that historical landownership fragmentation is uncorrelated with the option's underlying asset quality. Two arguments yield support in favor of this assumption. First and foremost, the majority of original landownership rights were allocated through federal allotments, rather than through individual purchases.[19] This suggests that historical landownership fragmentation should be mostly unrelated to the *total* value of the land, not to mention the mineral rights value of the parcels. Furthermore, 89% of the historical landowners in our sample acquired their land patents prior to 1910, which predates much of the oil and gas boom in the early 1900s (see Figure 1) and is over a century before the fracking revolution in the 2000s (see Figure 2). Together, these features suggest that the allocation of subsurface rights to initial landowners is orthogonal to the shale oil and gas potential of the land.

Second, in Panel A of Table 8, we empirically test whether historical landownership fragmentation is correlated with a measure of the option's underlying asset quality. Specifically, we investigate this relation using the market value of a section's first drilled. Consistent with the above assumption, we find no statistically significant effect. For example, the p-value

[19] Only 39% of the landowners in the Bureau of Land Management data for Oklahoma and Louisiana acquired parcels of land through cash-entry programs. The remaining 61% were allocated ownership rights under the Homestead Act of 1962, the Indian Allotment Act, and the Script Warrant Act.

in Model (2) equals 0.51. Further, the size of coefficient of interest is trivial in magnitude ($\beta = -0.001$). Although no empirical evidence can unequivocally satisfy the exclusion restriction, these results are reassuring.

Tchetgen Tchetgen et al. (2015) show that two-stage least square estimation procedures in which the second stage is non-linear (e.g., Cox regressions) yield unbiased coefficients. However, no statistical software readily includes such an approach. Thus, because the instrumented variable is a generated regressor, we must perform an adjustment to provide the proper statistical inference based on the second stage standard errors. To do so, we employ a bootstrap-based inference strategy with 500 iterations.

Panel B of Table 7 reports the second-stage Cox regression results. In each model, the coefficients on *Instrumented Unexercised Investment Opportunities (Peers)* are statistically significant at least at the 10% level. Model (1) presents results that correspond to the initial baseline results in Table 2. The coefficient in Model (1) is -0.271 with a hazard impact percentage of -23.76%. Models (2) and (3) correspond to the baseline results in Table 2 with additional control variables. In particular, the coefficient in Model (3) is -0.300, which corresponds to a hazard impact percentage of -25.94%, and is significant at the 5% level. This indicates that a one-standard-deviation change in *Instrumented Unexercised Investment Opportunities (Peers)* is equivalent to a 48.5% reduction in exercise likelihood. Finally, the Kleibergen-Paap first-stage F-statistics in Model (3) is 11.40, which mitigates a weak instrument concern. In all, our instrument variables analysis suggests that the impact of information anticipation on investment timing decisions is likely to be causal.

It is worth noting that the dominant OVB problem in our setting is likely to be positive—a case of affirmative endogeneity (Jiang, 2017). In other words, the coefficients in the second-stage regressions being more negative than those in the reduced form regressions is in line with our instrumented estimates moving toward the true value rather than away from it. To formalize this intuition, one can decompose the OLS beta into two parts, (a) the true beta, and (b) the omitted variable bias. Specifically, this is

$$\beta_{OLS} = \beta_{True} + \underbrace{\beta_{\text{Asset Quality}} \times cov(\text{Peer Options, Asset Quality})}_{\text{Omitted Variable Bias}} \tag{3}$$

Then, it is clear that the sign of the omitted variable bias depends on two parameters: $\beta_{\text{Asset Quality}}$ and cov(Peer Options, Asset Quality). It is reasonably safe to conclude that more valuable projects are more likely to be exercised (i.e., $\beta_{\text{Asset Quality}} > 0$). Conversely, it is not immediately obvious whether the covariance between the number of peer options and the value of the underlying asset is negative or positive. On one hand, larger numbers of peer options clustered around a firm's assets may be positively associated with the underlying asset quality. On the other hand, large groups of idle unexercised options located in close proximity to a project might be negatively correlated with the expected value of the project.

Empirically, we observe a positive relation, which is consistent with the underlying assumption in Chamley and Gale (1994) that the expected return of the project is increasing in the number of options. In particular, Panel A of Table 8 reports linear regression models that analyze the relationship between the number of peer real options in a project's vicinity and the market value of a section's first drilled well. Though the effect in Model (2) is insignificant at conventional levels (p-value=0.12), the coefficient on *Unexercised Investment Opportunities (Peers)* in Model (1) is positive and significant at the 1% level. Thus, overall, it is likely that the combined OVB term has a positive sign, suggesting that our reduced form coefficients underestimate the true magnitude.[20]

[20] The ratio between the instrumented coefficient in Model (1) of Table 7 and the reduced form Cox regression coefficients in Model (1) of Table 2 is 7.9. This magnitude is below the range reported in Jiang (2017) for affirmative endogeneity instruments.

7 Options Ownership Concentration and Aggregate Investment

The results in Sections 5 and 6 show that the anticipation of information release creates incentives for firms to wait for peers' investment decisions. As Chamley and Gale (1994) point out, such an information-induced delay must be inefficient in equilibrium.[21] Consistent with this, we show a 14-month delay for projects with nearby peer options costs the firm nearly $180,000 on the average project, with negligible observed benefits to waiting. While our calculations almost certainly overlook additional unobservable benefits, such as reduced uncertainty, it is possible that these informational externalities are inefficient at the firm level, and that they negatively impact aggregate investment, and ultimately, production.

We explore this in the context of total investment at the regional level. That is, we conduct a pure cross-sectional analysis to study the total number of options exercised over the entire sample period of 2005 through 2020. One obvious concern is that different regions developed earlier than others, which could impact both the expected amount of information from peers, as well as the total investment made. However, to control for this potential confounding dynamic, we include a region cohort-year fixed effect. This captures the year in which the first section was held by production, e.g., the first option became available in that region.

Because the total number of options exercised by all firms in a geographic area is mechanically related to the total number of options held (and thus, held by peers), we measure expected information release slightly differently than in our main analysis. That is, we define a new variable, *Options Ownership Concentration*, which resembles an option-ownership Herfindahl-Hirschman Index (HHI). Specifically,

[21] Other studies that model investment in similar settings have also shown delays to be inefficient, e.g., see Bolton and Harris (1999) and Acemoglu et al. (2011).

$$Options\ Ownership\ Concentration_k = \sum_i \left(\frac{Options_i}{Total\ Options_k} \right)^2 \quad (4)$$

where i denotes firms that hold at least one option in the region, k denotes a township.[22] The intuition behind such a measure is that the less concentrated options ownership is within a region, the more sources of expected information any one given firm is exposed to. Thus, while not identical to our main measure for the options-level analysis, it should capture the aggregate incentives in a very similar way.

The cross-sectional cut of the data leaves us a sample of 1,044 region observations. Table 9 displays the results. In our most stringent models, we include region cohort-year by county fixed effects.[23] Such a strategy should soak up the majority of variation that may be related to the underlying asset value, as well as any differential development effects. However, we also control for the cumulative number of options available in the region. This is important, as it allows us to identify the effect of local ownership concentration on the number of options exercised after controlling for the number of options that are available to be drilled. Finally, we add controls for the region's average market value and drilling costs per well. We continue to cluster our standard errors at the county level.

The coefficients in Table 9 are each statistically significant at the 1% level. Further, they suggest that the economic magnitude of the effect is large. Model (3) implies that a one-standard deviation decrease in options ownership concentration is related to a decrease of 0.74 options exercised per region. Given the unconditional sample average is 3.84 options exercised by the end of the sample, this represents a 19% decrease in total aggregate investment.[24]

[22]This variable is measured during the last year in which a region is in our sample. However, our results are not sensitive to this timing decision and remain qualitatively similar using the time period's mean or median concentration, as well as using the region's concentration 12 months after the initial option is developed.

[23]Because singletons are dropped from the model, including this set of fixed effects reduces the sample size to 767 region observations.

[24] $\frac{\beta_{\text{Concentration}} \times \sigma_{\text{Concentration}}}{\mu_{\text{Total No. of Exercised Options}}} = \frac{1.74 \times 0.42}{3.84} = 0.19$

These results suggest that strategic learning incentives significantly impact total aggregate investment. Moreover, it is likely that these distortions flow through investment and also affect aggregate production on the extensive margin: the local drilling intensity. To get a rough sense of the lost production, in both oil and gas, and in monetary terms, we conduct a crude back-of-the-envelope calculation. We start with the total production associated with the average drilled well in our sample, which is equal to 281,143 barrels of oil equivalent (BOE). Further, 463 of the 767 townships in Model (3) have an options ownership concentration of at least one-standard deviation less than the max (100% concentration). Then, a lower bound on the total lost production over our sample relative to a counterfactual in which firms expect no information release from peers can be calculated as follows, $463 \times 0.74 \times 281,143 = 96,325,215$ BOEs. With a sample average price of \$60 per barrel, this suggests that roughly \$5.8 billion in oil and gas production has been lost due to strategic learning incentives since 2005 in Louisiana and Oklahoma alone.

8 Robustness

Our results in Section 5 consistently show a relationship between possible information spillover and the timing of firms' investment. This remains the case despite empirical specifications that include a comprehensive set of control variables and county-level (geographic) strata. Moreover, in Section 6, we argue that this relationship is likely to be causal. However, it could be the case that poor projects are driving our results. Further, it is possible that some portion of the effect we document is spurious. Finally, as with any empirical study, a number of our modeling decisions stem from somewhat subjective choices (e.g., level of clustering). This section explores several additional empirical specifications that investigate the sensitivity of our main results to such critiques.

First, in an ultimate test of Chamley and Gale (1994), we turn to a subsample analysis to show empirical specifications that satisfy both of the conditions highlighted in Proposition

4 of their paper ($\delta W(\xi, h) > v(h) > 0$). That is, to cleanly measure the effect of *pure* learning incentives net of the effect of project quality, we need an empirical setting in which firms decide to delay their investment decisions even if exercising immediately is deemed profitable in expectation. To do so, we ideally need to identify options that are expected to be profitable upon exercise (i.e., $v(h) > 0$).

We focus on a subsample of our data that contains only options associated with the most positive signal of peers' option quality. While it is not possible to observe a firm's information set, limiting the sample to only options located in the most prolific geographic regions offers a reasonable alternative to capture cases in which firms are likely to expect their investment to be NPV positive if exercised immediately. Table 10 reports the results of this subsample test. Specifically, in these empirical specifications, we include only firm options located in regions in which the market value of the average drilled peer well is above the sample median. This leaves us with a reduced sample of 270,383 option-month observations covering 6,418 unique options.

The results in Table 10 support the argument that we are capturing the impact of pure learning incentives, rather than that of poor project quality.[25] In particular, both the economic and statistical significance of the subsample results are very similar to those in our main analysis. In sum, it appears that firms delay the exercise of *valuable* projects in anticipation of information spillover from peer decisions and outcomes.

Next, we attempt to rule out the possibility of spurious results. It could be the case, for example, that the number of unexercised investment opportunities held by a firm's peers is correlated with broad market conditions in the oil and gas industry. While we control for variables that should proxy for these conditions (e.g., the underlying asset futures prices); if they do a poor job, the relationship between a firm's peers' unexercised options and those

[25] Further consistent with this idea, the results in Table 4 suggest that unexercised peer options induce a delay over almost the full support of the interaction with the market value of peers' wells. The exception is at the very extremes, e.g., when there is only one peer option *and* the average market value of peer wells is in the 99^{th} percentile. In other words, firms wait to learn from their peers even when they receive one of the strongest possible signals that their project is NPV positive.

of the firm itself may simply reflect a decline in the demand for oil and gas.

To investigate such an alternative explanation of our results, we design a falsification test. That is, we define a new variable that is similar to the original measure in that it includes real options held by a firm's peers. However, in this case, we alter the distance definition of a firm's peers to be between 10 and 13 miles from the project. Thus, it includes real options that are, broadly speaking, located in the same geographic area and are certainly in the same shale play. However, because of the reduction in geographic proximity, these are options that should contain less relevant information for a firm's specific exercise decision. Thus, significant results would likely suggest a degree of spuriousness.

Table 11 reports the results of this falsification test. All three specifications soundly reject such an explanation of our results. In particular, each model shows coefficients on the falsified variable that are statistically indistinguishable from zero. Further, the economic magnitudes of the coefficients are trivial. In all, Table 11 mitigates concerns of spurious results.

Next, we further consider alternative definitions of the maximum distance a well can be located from a firm's option and still be considered a peer option. While we choose three miles in our main specifications to mimic the size of a township, there is little to prevent a firm from learning from option exercise of wells located just outside that distance. Table 12 displays results that vary this distance definition. In particular, Model (1) defines the peer distance to be 2 miles rather than our main definition of 3, while Model (3) defines the peer distance to be 4 miles. Model (2) re-reports the main results we present in Table 2 using the distance definition of 3 miles.

The results in all three specifications are qualitatively and quantitatively similar, suggesting our main inferences are not sensitive to the exact distance we use to define a firm's peers. In particular, all three of the distance specifications suggest that a one-standard-deviation increase in peers real options is associated with 10-14% reduction in exercise likelihood.

Finally, the Internet Appendix reports tables from a series of empirical specifications that show our results are robust to other econometric modeling techniques. In particular, the inference from the following models remain qualitatively similar:

(i) Indicator variable approach to measuring potential information spillover (Table IA.1)
(ii) Results from the reduced sample with data on historical landownership (Table IA.4)
(iii) Reduced form linear regression models (Table IA.5)
(iv) Reduced form probit regression models (Table IA.5)
(v) Two-stage least squares (linear-linear) regression models (Table IA.5)
(vi) Two-stage least squares (linear-probit) regression models (Table IA.5)
(vii) Models that cluster standard errors by firm rather than county (Table IA.6)

9 Conclusion

In this paper we exploit detailed project-level data and arbitrary variation in the historical fragmentation of landownership rights to identify the causal impact of *potential* information spillover on corporate investment decisions. We find that each additional real option held by a firm's peers significantly influences the timing of the firm's own investment decisions, as the firm looks to reduce uncertainty by first observing its peers' outcomes. The associated investment delays induced by firms' strategic incentives can be large. Ultimately, the anticipation of information dampens investment and production at the aggregate level. Overall, we highlight novel learning incentives, even prior to information being released, that have important implications for optimal disclosure regulations.

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Figure 1: Historical Oil and Gas Production in the State of Oklahoma. This figure displays the number of barrels produced per day in the state of Oklahoma, for the period 1900 to 2000. Source: Claxton, Larry (ed.), 2001, Oil and gas information: Oklahoma Corporation Commission Web site: http://www.occ.state.ok.us/text_files/o&gfiles.htm

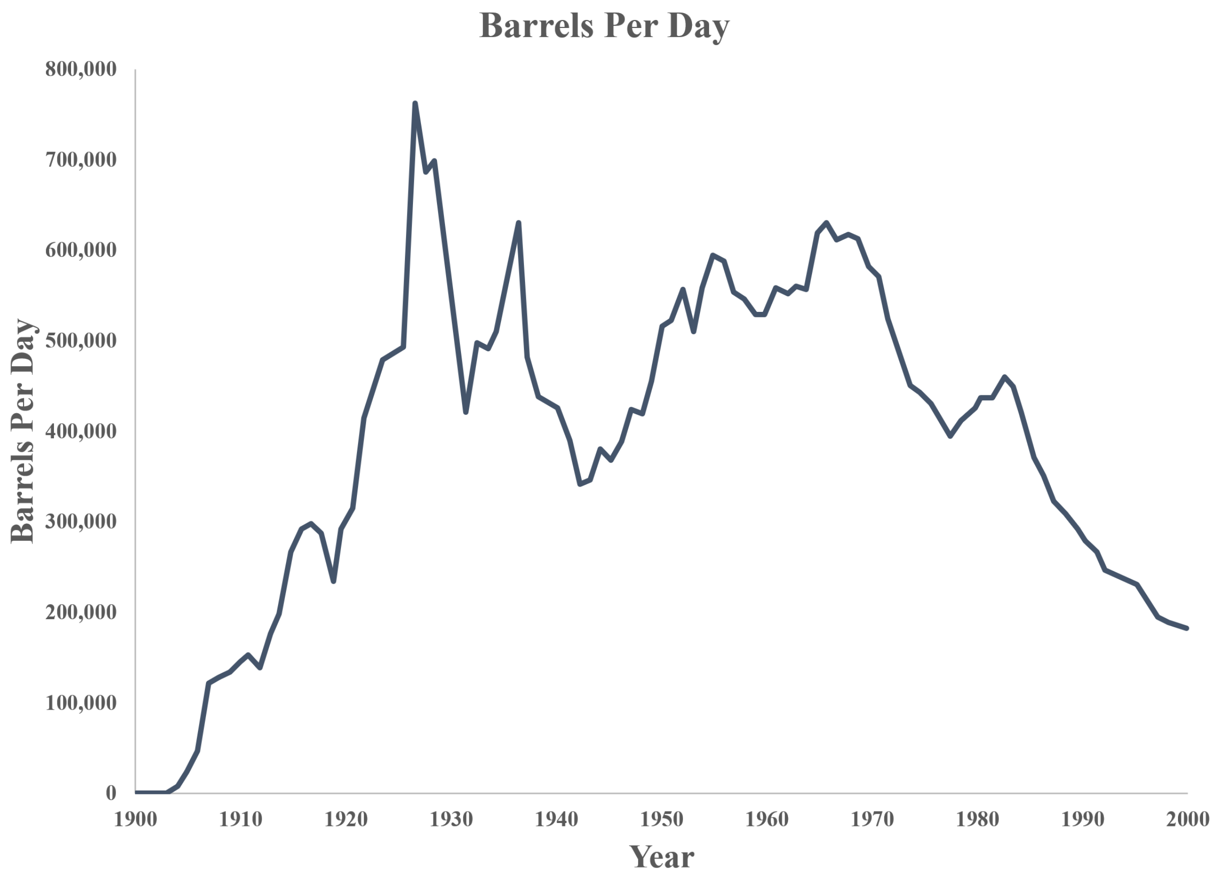


Figure 2: Evolution of the Drilling Technology Used for Oil and Gas Wells. This figure displays the number of wells drilled for the vertical and horizontal drilling technology on the period 2000 to 2020. The red and blue lines respectively indicate the number of horizontal and vertical wells drilled in a given month.

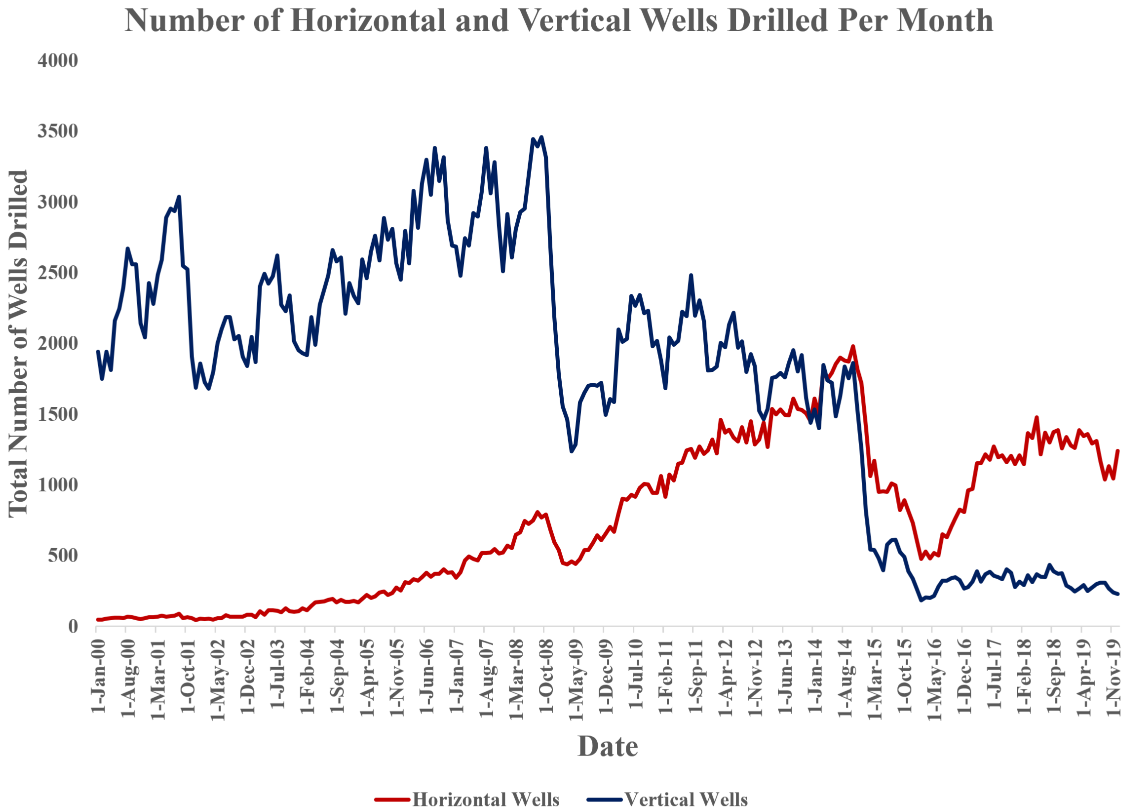


Figure 3: Shale Plays Across the U.S. This figure displays the location of shale resources across the United States as of June 2016. For our analysis, we focus on the shale plays located in Louisiana and Oklahoma. *Source*: U.S. Energy Information Administration.

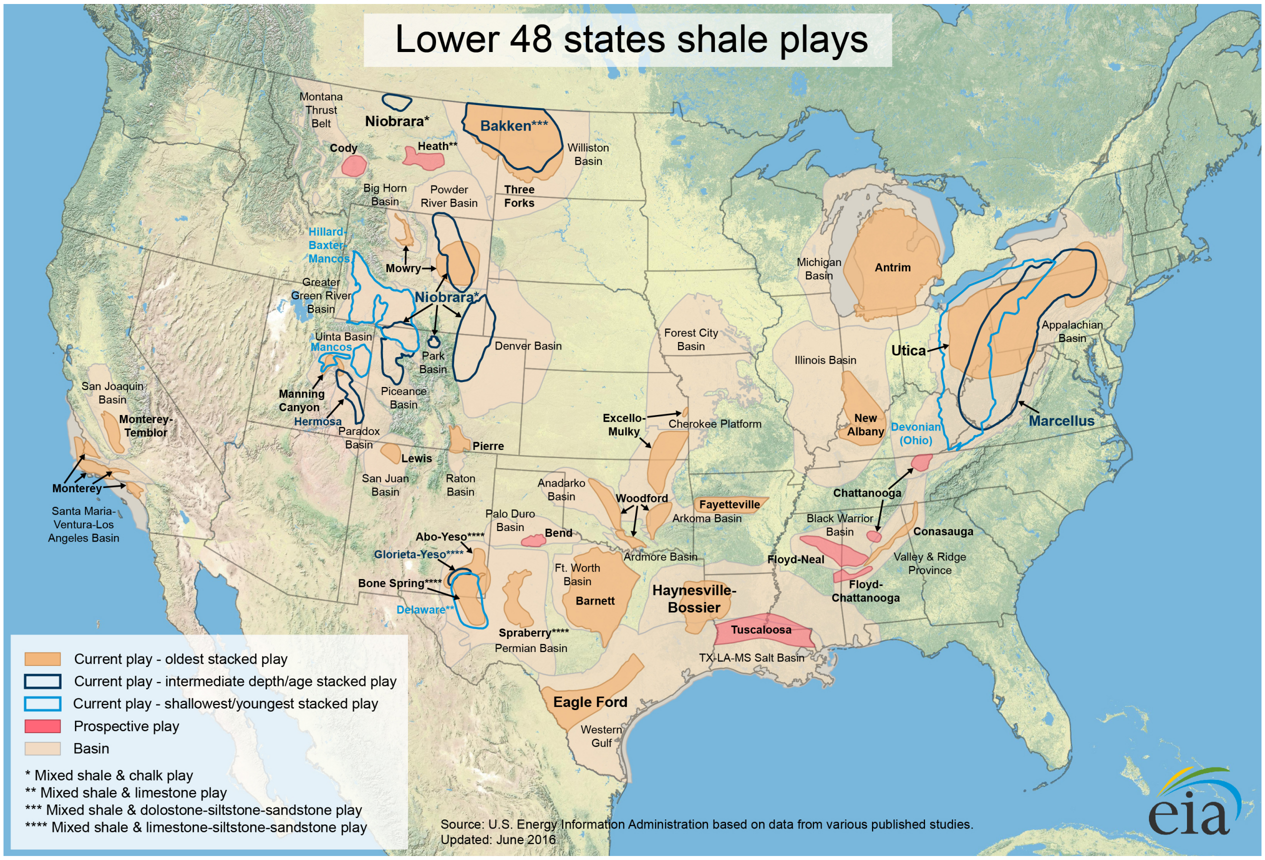


Figure 4: Louisiana and Oklahoma Institutional Features. This figure shows how land surveying methods, and land spacing requirements differs across states. The land survey method in Louisiana and Oklahoma, in contrast to Texas for example, was conducted using the rectangular survey system. This is reflected in this picture by having 36 standardized 1 miles by 1 miles sections per township. This provides us with a well define land unit in the analysis. Further, all states have different spacing requirements for horizontal wells (i.e., the minimum amount of acres to be acquired by a firm to drill a well). Conveniently, Louisiana and Oklahoma both require oil and gas companies to acquire the leasing rights to 640 acres, or the size of a section, to begin drilling activities. Combined, these features provide us with a clean unit of measurement for the real options in our sample.

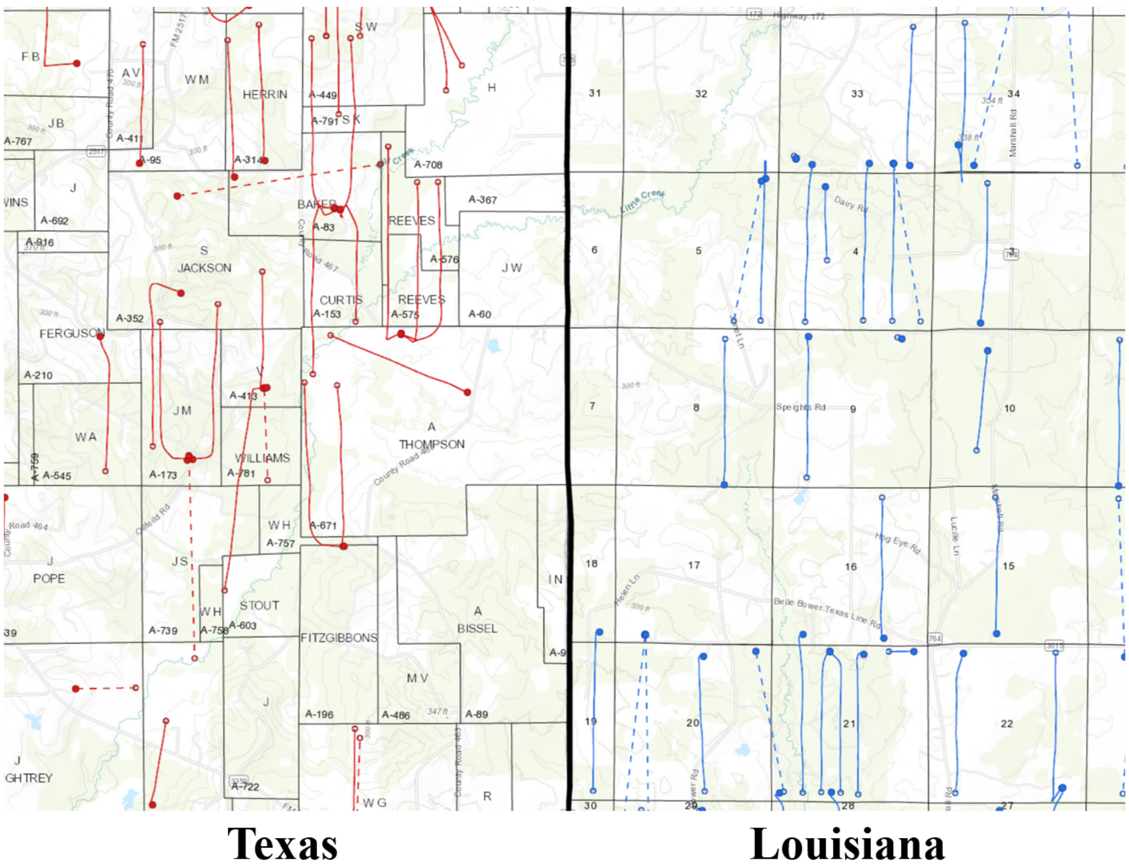


Figure 5: Example of Section and Options in the Context of Horizontal Wells. This figure presents a visual example of a section, a section that is held-by-production, and one that has been exercised.

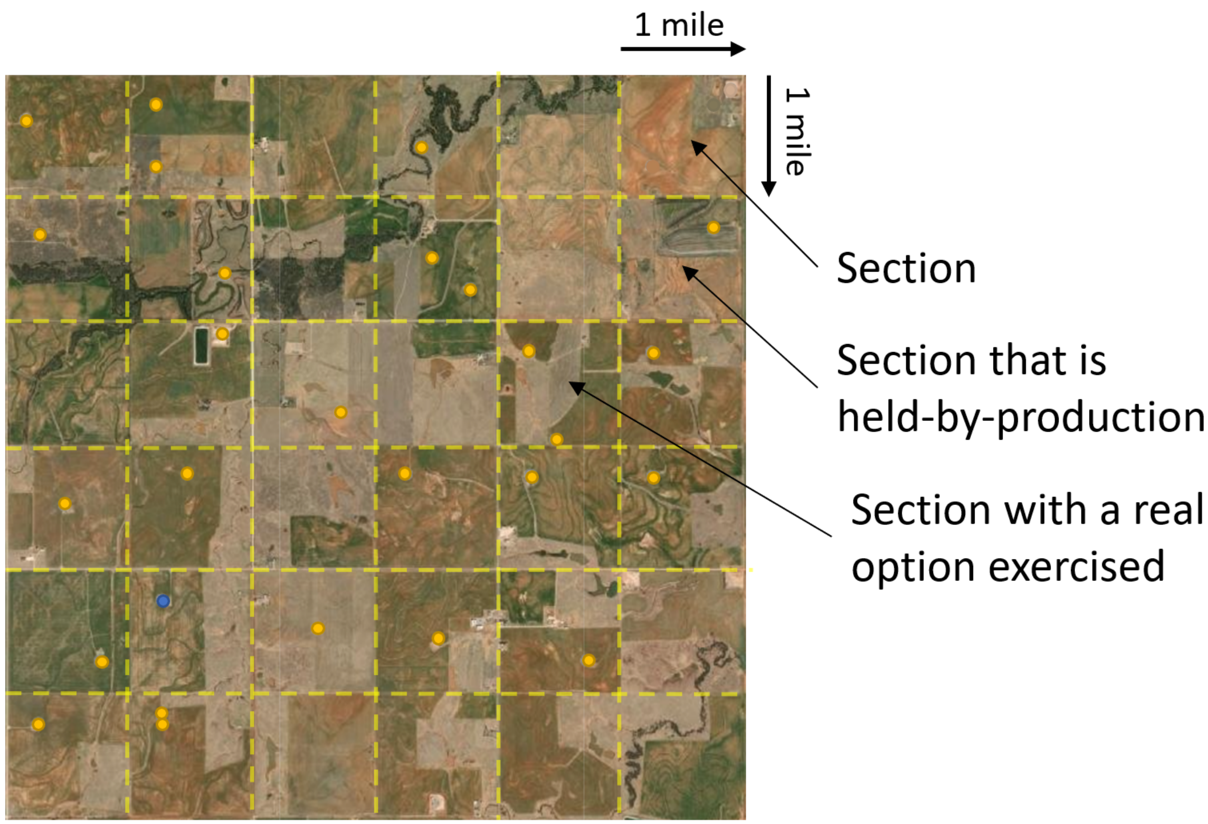


Figure 6: Average Life of Wells as of January 2020. This graph shows the average age of wells drilled during a specific year, as well as the proportion of those wells that are still in production.

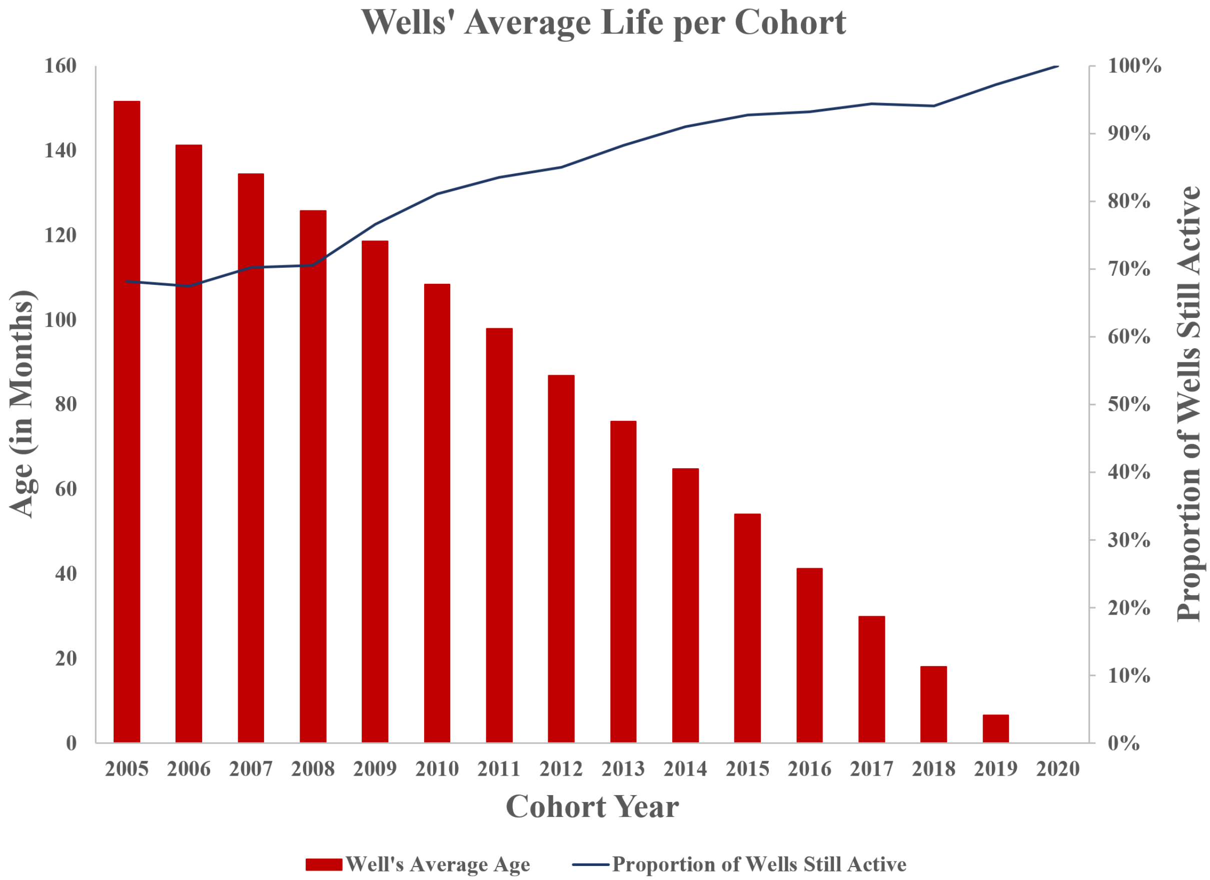


Figure 7: Identifying Peers' Available Options. This figure displays the intuition of the construction of our main variable of interest, *Unexercised Investment Opportunities (Peers)*. Each blue dot depicts a well dug by the firm in question, while each yellow dot represents a well dug by the firm's peers. As depicted in Figure 4, each section with only 1 well dug is defined as a real option. For an available option held by a peer to be counted in our variable of interest, it must be located within 3 miles from the option. Thus, for a section to be considered a peers' option for the firm option highlighted in red, it must be located within the outer blue line and have an initial well dug (e.g., 1 yellow dot). In the current example, there would be 21 such available peer options the firm could learn from when they get exercised.

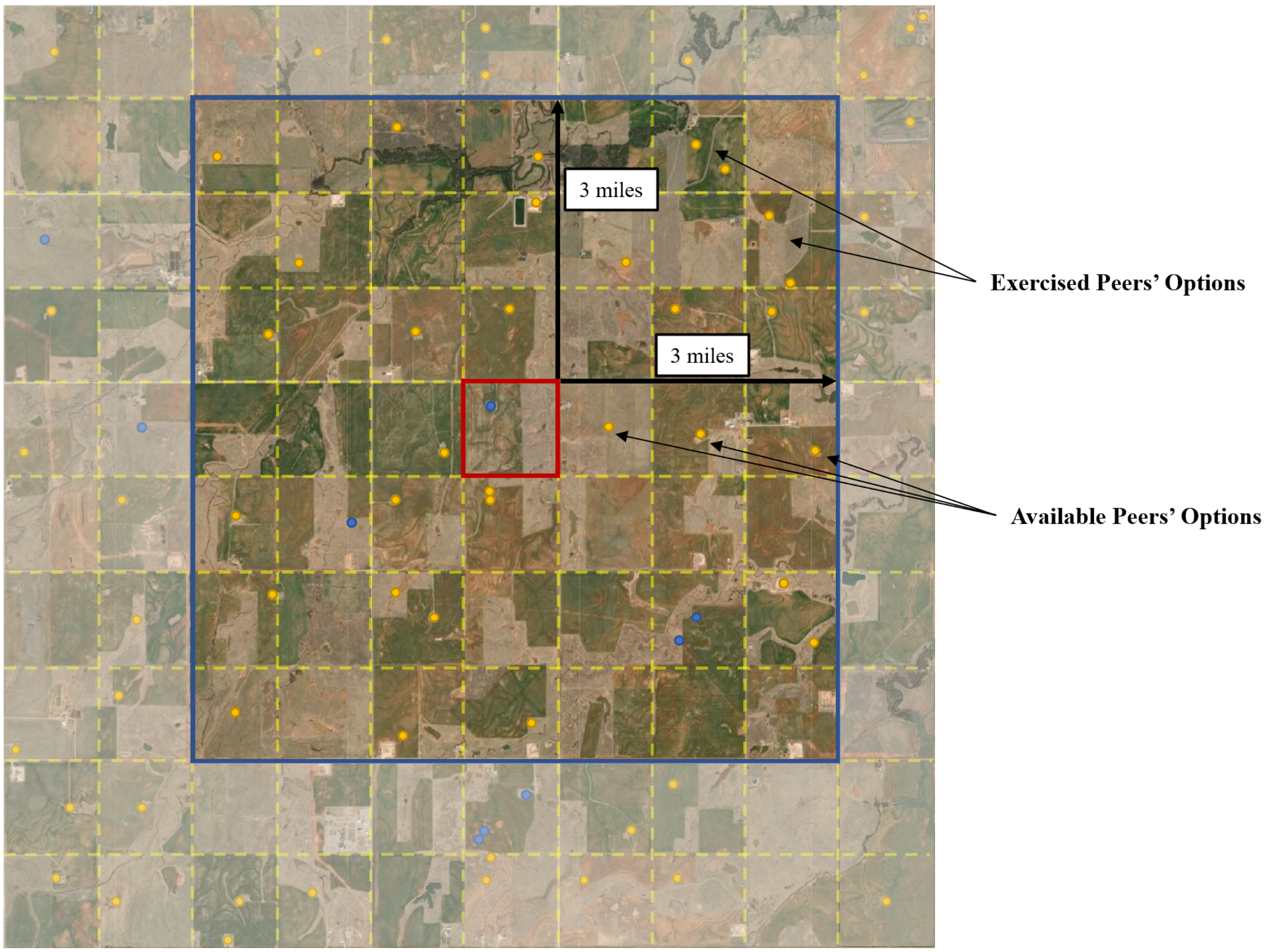


Figure 8: Peer Options and Project Exercise. This figure plots the survival function, measured by the proportion of infill drilling options that remain unexercised (i.e. that have "survived') over our sample period from 2005 through 2020. The *No Peer Options* line represents the survival function for the subset of options that did not have any peer options located within 3 miles during the full life of the option. The *At Least One Peer Option* line represents the survival function for the subset of options that had at least one peer option located within 3 miles at any point during life of the option.

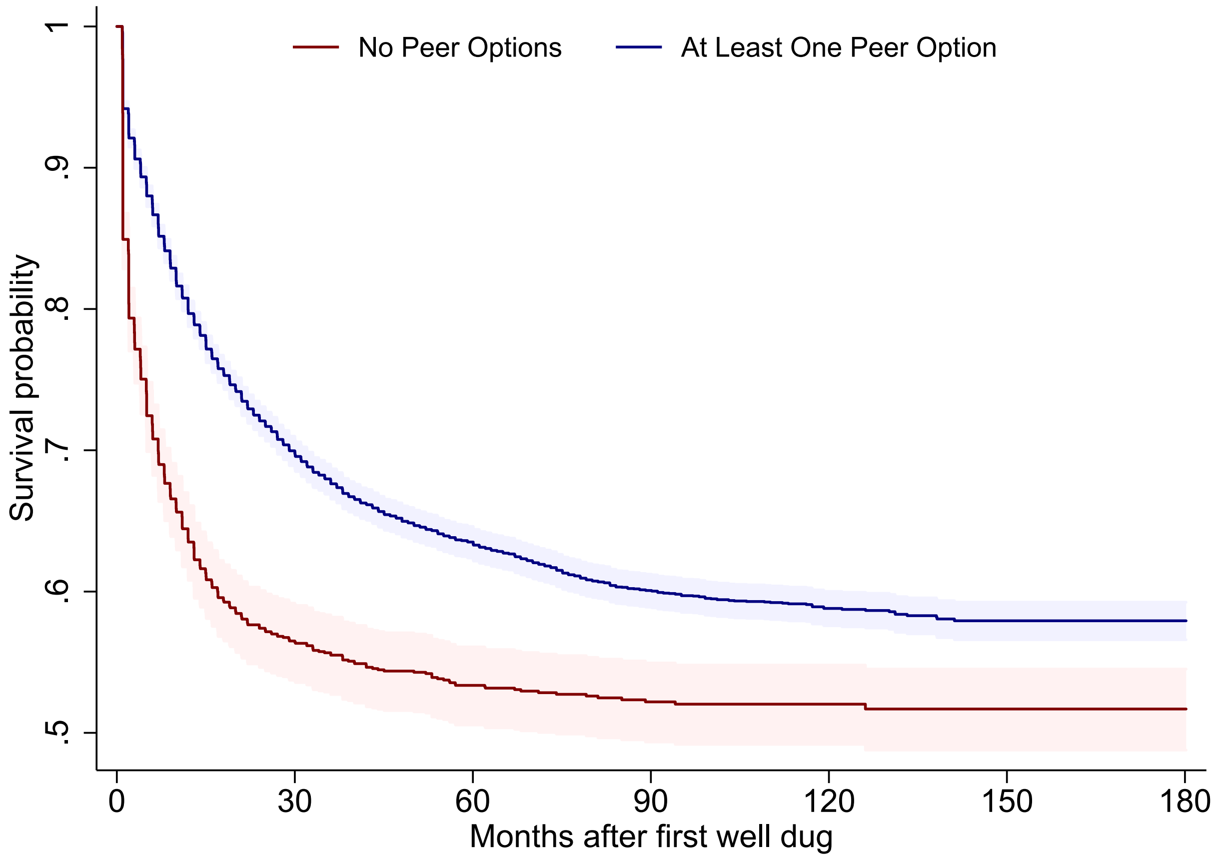
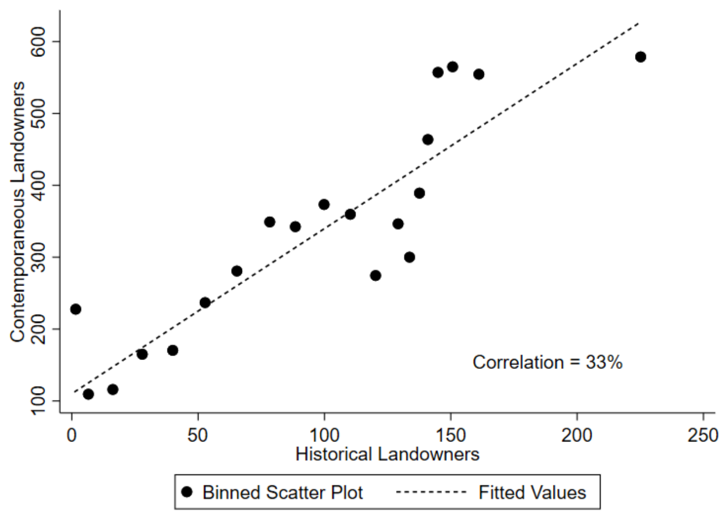
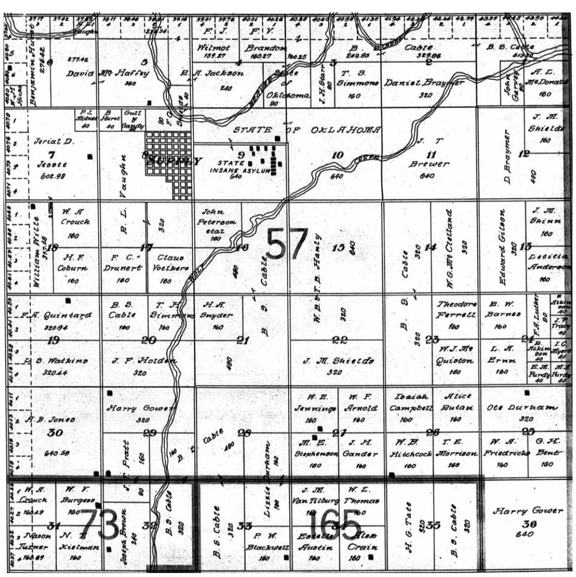


Figure 9: Instrumental Variable Construction and Intuition. Figure (A) presents the correlation between the number of historical and contemporaneous landowners in our sample. To mitigate the effect of outliers, each is winsorized at the 1% and 99% levels. Figures (B) and (C) present distinctive examples of how individual property ownership can fragment the land. The figures are from two townships in Woodward County, Oklahoma in 1910. In Figure (B), each landowner possesses the drilling rights to twelve sections, while in Figure (C), a landowner has the rights to only four sections. The more sections a specific owner controls, the easier it becomes for oil and gas companies to collect the drilling rights to multiple contiguous plots of land before competitors frustrate their efforts. Source Information: Ancestry.com. U.S., Indexed County Land Ownership Maps, 1860-1918.

(A) Landowners Through Time. This figure presents the correlation between the number of historical landowners in townships and the number of contemporaneous landowners at the time the mineral rights leases are acquired in our sample.



(B) Low Historical Landownership Fragmentation. This figure presents the historical landownership fragmentation of the township 21N-18W, Oklahoma.



(C) High Historical Landownership Fragmentation. This figure presents the historical landownership fragmentation of the township 24N-12W, Oklahoma.

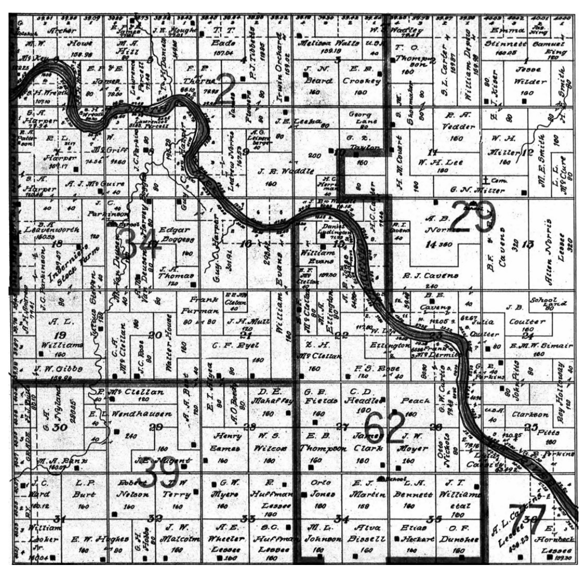


Table 1: Summary Statistics. This table reports the summary statistics. Data on horizontal wells are from DrillingInfo, while data for the remaining covariates are taken from Bloomberg, St. Louis Federal Reserve Bank, and publicly available firm reports. *Peers' Wells' Value*, *Mean Distance Between Options*, *First Well's Market Value*, and *Drilling Costs* are reported in their unlogged form. *Historical Landowners Fragmentation* and *Contemporaneous Landowners Fragementation* are measured at the tonwship level. All variables are defined in Table A1.

	Mean	25^{th} Pct.	Median	75^{th} Pct.	Std. Dev.	No. Obs.
Regional Variables						
Unexercised Investment Opportunities (Peers)$_{j,t}$	3.93	1.00	3.00	6.00	3.66	540,765
Cumulative Number of Well's Drilled$_{j,t}$	17.30	8.00	17.00	25.00	11.06	540,765
Unexercised Investment Opportunities (Own)$_{j,t}$	4.88	2.00	4.00	7.00	3.96	540,765
Peers' Wells' Value$_{j,t}$ ($Ms)	3.18	1.23	2.42	4.56	2.72	540,765
Firm Level Variables						
Firm Drilling Activity$_{i,t}$ (Annual)	0.89	0.00	0.00	0.00	4.46	540,765
Mean Distance Between Options$_{i,t}$ (Miles)	140.95	31.35	100.75	215.30	134.08	540,765
Portfolio Concentration$_{i,k,t}$	0.37	0.12	0.25	0.52	0.31	540,765
Total Number of Options Per Firm$_i$	19.45	1.00	3.00	11.00	82.68	451
Number of Firms	**451**					
Well Level Variables						
First Well's Market Value$_{j,t}$ ($Ms)	3.19	0.79	2.01	4.54	3.61	540,765
Drilling Cost$_{j,t}$ ($Ms)	4.21	3.41	4.50	5.05	1.95	540,765
Well Lateral Length$_{j,t}$ (1,000 ft.)	4.34	3.62	4.71	4.95	1.95	540,765
Oil-to-Gas Ratio$_j$	0.30	0.00	0.14	0.59	0.34	540,765
Financial Market Variables						
18-Month Oil Futures Price$_t$	69.47	53.09	62.74	88.36	18.97	540,765
18-Month Oil Futures Implied Volatility$_t$	26.44	23.13	26.95	30.57	5.33	540,765
10-Year Risk Free Rate$_t$	2.45	1.97	2.35	2.81	0.64	540,765
Cost of Equity$_t$ (Oil and Gas Industry β)	1.16	1.11	1.21	1.27	0.15	540,765
Landownership Variables						
Historical Landowners Fragmentation$_k$	94.74	45.00	105.00	139.00	55.56	2,046
Contemporaneous Landowners Fragmentation$_k$	327.65	45.00	203.00	460.00	386.44	2,046

Table 2: Peer Options and Project Exercise. 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 Table A1. 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)$_{j,t}$	-0.030***	-2.93	-0.037***	-3.59	-0.037***	-3.66
	(0.011)		(0.011)		(0.010)	
Cumulative Number of Well's Drilled$_{j,t}$	0.053***	5.41	0.048***	4.97	0.052***	5.29
	(0.004)		(0.004)		(0.004)	
Unexercised Investment Opportunities (Own)$_{j,t}$	-0.036***	-3.51	-0.043***	-4.22	-0.053***	-5.17
	(0.011)		(0.011)		(0.010)	
Portfolio Concentration$_{i,k,t}$	0.199	22.04	0.131	14.00	0.089	9.35
	(0.180)		(0.172)		(0.162)	
Mean Distance Between Options$_{i,t}$	-0.056	-5.40	-0.061*	-5.96	-0.072**	-6.91
	(0.037)		(0.035)		(0.034)	
Firm Skill Level$_{i,t}$	-0.028	-2.79	-0.235***	-20.91	-0.183**	-16.72
	(0.057)		(0.082)		(0.083)	
First Well's Market Value$_{j,t}$			0.222***	24.89	0.202***	22.35
			(0.066)		(0.060)	
Peers' Wells' Value$_{j,t}$			0.061***	6.33	0.058***	5.96
			(0.015)		(0.014)	
Oil-to-Gas Ratio$_{j}$			0.306**	35.82	0.360***	43.27
			(0.129)		(0.124)	
Drilling Cost$_{j,t}$			-0.068**	-6.60	-0.051**	-5.00
			(0.027)		(0.024)	
Futures Price$_{t}$					0.008***	0.85
					(0.003)	
Implied Volatility$_{t}$					-0.035***	-3.41
					(0.007)	
10-Year Risk Free Rate$_{t}$					0.135**	14.44
					(0.060)	
Cost of Equity$_{t}$					-0.700**	-50.36
					(0.282)	
County Strata	Yes		Yes		Yes	
$Pseudo - Loglikelihood$	-17,331		-17,224		-17,108	
Wald Chi^2	397		522		1,024	
Observations	540,765		540,765		540,765	

Table 3: Peer Options, Diminishing Marginal Impact, and Project Exercise. 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. This table also investigates the possibility that the relationship between peer options and project exercise is not linear. Panel A focuses on a quadratic function approach (adds the square of *Unexercised Investment Opportunities (Peers)*). Panel B adds an interaction between peer options and *I(Peers' Options* ≤ 3*)*, which is an indicator variable that equals 1 if *Unexercised Investment Opportunities (Peers)* ≤ 3, and 0 otherwise. 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. Robust standard errors, clustered at the county level, are reported in parentheses. *,**, and *** denote significance at the 10%, 5%, and 1% level, respectively.

Panel A: Quadratic Function Approach

	Hazard Model for Project Exercise			
	(1)		(2)	
	Estimates	HI(%)	Estimates	HI(%)
Unexercised Investment Opportunities (Peers)$_{j,t}$	-0.058***	-5.67	-0.076***	-7.31
	(0.015)		(0.015)	
Unexercised Investment Opportunities (Peers)$^2_{j,t}$	0.002**	0.22	0.003***	0.30
	(0.001)		(0.001)	
Cumulative Number of Well's Drilled$_{j,t}$	0.053***	5.48	0.052***	5.37
	(0.004)		(0.004)	
Unexercised Investment Opportunities (Own)$_{j,t}$	-0.036***	-3.55	-0.054***	-5.26
	(0.011)		(0.010)	
Portfolio Concentration$_{i,k,t}$	0.200	22.14	0.089	9.32
	(0.178)		(0.161)	
Mean Distance Between Options$_{i,t}$	-0.055	-5.34	-0.071**	-6.87
	(0.037)		(0.034)	
Firm Skill Level$_{i,t}$	-0.025	-2.49	-0.183**	-16.74
	(0.057)		(0.083)	
First Well's Market Value$_{j,t}$			0.203***	22.46
			(0.060)	
Peers' Wells' Value$_{j,t}$			0.060***	6.23
			(0.014)	
Oil-to-Gas Ratio$_j$			0.358***	43.07
			(0.125)	
Drilling Cost$_{j,t}$			-0.051**	-4.97
			(0.024)	
Futures Price$_t$			0.008***	0.84
			(0.003)	
Implied Volatility$_t$			-0.035***	-3.42
			(0.007)	
10-Year Risk Free Rate$_t$			0.131**	14.02
			(0.059)	
Cost of Equity$_t$			-0.692**	-49.94
			(0.284)	
County Strata	Yes		Yes	
$Pseudo-Loglikelihood$	-17,328		-17,103	
Wald Chi^2	494		1,613	
Observations	540,765		540,765	

(*Continued*)

Table 3—*Continued*

Panel B: Indicator for Low Number of Peers' Options Approach				
	Hazard Model for Project Exercise			
	(1)		(2)	
	Estimates	HI(%)	Estimates	HI(%)
Unexercised Investment Opportunities (Peers)$_{j,t}$	-0.023	-2.27	-0.028**	-2.77
	(0.015)		(0.014)	
Unexercised Inv. Opp. (Peers)$_{j,t}$ × I(Peers Options' ≤ 3)	-0.039	-3.85	-0.067**	-6.44
	(0.026)		(0.029)	
I(Peers' Options ≤ 3)	0.106	11.20	0.159*	17.22
	(0.088)		(0.087)	
Cumulative Number of Well's Drilled$_{j,t}$	0.053***	5.46	0.052***	5.36
	(0.004)		(0.004)	
Unexercised Investment Opportunities (Own)$_{j,t}$	-0.036***	-3.52	-0.054***	-5.21
	(0.011)		(0.010)	
Portfolio Concentration$_{i,k,t}$	0.203	22.50	0.095	9.93
	(0.179)		(0.161)	
Mean Distance Between Options$_{i,t}$	-0.055	-5.31	-0.071**	-6.81
	(0.037)		(0.034)	
Firm Skill Level$_{i,t}$	-0.026	-2.61	-0.185**	-16.90
	(0.057)		(0.083)	
First Well's Market Value$_{j,t}$			0.202***	22.34
			(0.060)	
Peers' Wells' Value$_{j,t}$			0.061***	6.34
			(0.014)	
Oil-to-Gas Ratio$_{j}$			0.357***	42.90
			(0.124)	
Drilling Cost$_{j,t}$			-0.050**	-4.92
			(0.024)	
Futures Price$_{t}$			0.008***	0.85
			(0.003)	
Implied Volatility$_{t}$			-0.035***	-3.40
			(0.007)	
10-Year Risk Free Rate$_{t}$			0.133**	14.21
			(0.060)	
Cost of Equity$_{t}$			-0.687**	-49.68
			(0.283)	
County Strata	Yes		Yes	
$Pseudo-Loglikelihood$	-17,329		-17,104	
Wald Chi^2	438		1,290	
Observations	540,765		540,765	

Table 4: Peer Options, Signal Quality, and Project Exercise. 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. This table also investigates the impact of the signal the firm receives from previously drilled peer wells. *Peers' Wells' Mkt. Value* proxies for the quality of the signal and is defined as the natural log of the mean well value amongst a firm's peers. 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. 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)	
	Estimates	HI(%)	Estimates	HI(%)
Unexercised Investment Opportunities (Peers)$_{j,t}$	-1.105***	-66.89	-0.784***	-54.36
	(0.158)		(0.146)	
Unexercised Inv. Opp. (Peers)$_{j,t}$ × Peers' Wells' Mkt. Value$_{j,t}$	0.070***	7.30	0.049***	5.05
	(0.011)		(0.010)	
Peers' Wells' Value$_{j,t}$	0.061***	6.27	0.054***	5.56
	(0.014)		(0.013)	
Cumulative Number of Well's Drilled$_{j,t}$	0.050***	5.16	0.051***	5.24
	(0.004)		(0.004)	
Unexercised Investment Opportunities (Own)$_{j,t}$	-0.039***	-3.83	-0.051***	-4.94
	(0.010)		(0.010)	
Portfolio Concentration$_{i,k,t}$	0.176	19.21	0.114	12.07
	(0.161)		(0.156)	
Mean Distance Between Options$_{i,t}$	-0.059	-5.74	-0.065*	-6.33
	(0.036)		(0.034)	
Firm Skill Level$_{i,t}$	-0.134**	-12.58	-0.202**	-18.32
	(0.067)		(0.084)	
First Well's Market Value$_{j,t}$			0.177***	19.37
			(0.059)	
Oil-to-Gas Ratio$_{j}$			0.357***	42.89
			(0.115)	
Drilling Cost$_{j,t}$			-0.049**	-4.79
			(0.023)	
Futures Price$_{t}$			0.008***	0.77
			(0.003)	
Implied Volatility$_{t}$			-0.034***	-3.38
			(0.007)	
10-Year Risk Free Rate$_{t}$			0.119*	12.61
			(0.062)	
Cost of Equity$_{t}$			-0.651**	-47.86
			(0.279)	
County Strata	Yes		Yes	
$Pseudo-Loglikelihood$	-17,239		-17,082	
Wald Chi^2	785		1,687	
Observations	540,765		540,765	

Table 5: Peer Options, Peers' Quality, and Project Exercise. 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. This table investigates the impact of peer quality on project exercise. *Unexercised Investment Opportunities (High-Skill Peers)* measures all options (within 3 miles) held by firms whose mean well produces an above-sample-median quantity of oil or gas. *Unexercised Investment Opportunities (Low-Skill Peers)* measures all options (within 3 miles) held by firms whose mean well produces a below-sample-median quantity of oil or gas. 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. 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)	
	Estimates	HI(%)	Estimates	HI(%)
Unexercised Investment Opportunities (High-Skill Peers)$_{j,t}$	-0.125***	-11.73	-0.151***	-13.97
	(0.041)		(0.040)	
Unexercised Investment Opportunities (Low-Skill Peers)$_{j,t}$	0.025	2.56	0.009	0.92
	(0.024)		(0.024)	
Cumulative Number of Well's Drilled$_{j,t}$	0.053***	5.43	0.052***	5.31
	(0.004)		(0.004)	
Unexercised Investment Opportunities (Own)$_{j,t}$	-0.037***	-3.62	-0.054***	-5.27
	(0.011)		(0.010)	
Portfolio Concentration$_{i,k,t}$	0.203	22.49	0.092	9.64
	(0.180)		(0.162)	
Mean Distance Between Options$_{i,t}$	-0.057	-5.52	-0.072**	-6.96
	(0.037)		(0.033)	
Firm Skill Level$_{i,t}$	-0.023	-2.28	-0.180**	-16.51
	(0.055)		(0.082)	
First Well's Market Value$_{j,t}$			0.204***	22.67
			(0.060)	
Peers' Wells' Value$_{j,t}$			0.057***	5.91
			(0.014)	
Oil-to-Gas Ratio$_{j}$			0.360***	43.28
			(0.124)	
Drilling Cost$_{j,t}$			-0.050**	-4.89
			(0.024)	
Futures Price$_{t}$			0.008***	0.85
			(0.002)	
Implied Volatility$_{t}$			-0.035***	-3.43
			(0.007)	
10-Year Risk Free Rate$_{t}$			0.125**	13.34
			(0.058)	
Cost of Equity$_{t}$			-0.720***	-51.31
			(0.279)	
Chi^2 (High Skill—Low Skill)	11.17***		12.09***	
(p-Value)	(0.001)		(0.001)	
County Strata	Yes		Yes	
Pseudo − Loglikelihood	-17,325		-17,104	
Wald Chi^2	431		1,106	
Observations	540,765		540,765	

Table 6: Peer Options, Project Similarity, and Project Exercise. 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. This table investigates the impact of project similarity of peer options on project exercise. *Unexercised Investment Opportunities (Same Resource)* measures all peer options (within 3 miles) that have the same majority (> 50%) resource (oil or gas) as the option in question, while *Unexercised Investment Opportunities (Different Resource)* measures all peer options (within 3 miles) that have a different majority resource as the option in question. 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. 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)	
	Estimates	HI(%)	Estimates	HI(%)
Unexercised Investment Opportunities (Same Resource)$_{j,t}$	-0.112***	-10.59	-0.140***	-13.03
	(0.035)		(0.033)	
Unexercised Investment Opportunities (Different Resource)$_{j,t}$	-0.026	-2.59	-0.035	-3.41
	(0.025)		(0.025)	
Cumulative Number of Well's Drilled$_{j,t}$	0.053***	5.40	0.051***	5.28
	(0.004)		(0.004)	
Unexercised Investment Opportunities (Own)$_{j,t}$	-0.035***	-3.48	-0.053***	-5.15
	(0.011)		(0.010)	
Portfolio Concentration$_{i,k,t}$	0.202	22.33	0.091	9.55
	(0.178)		(0.161)	
Mean Distance Between Options$_{i,t}$	-0.055	-5.38	-0.072**	-6.90
	(0.037)		(0.034)	
Firm Skill Level$_{i,t}$	-0.026	-2.61	-0.181**	-16.55
	(0.057)		(0.083)	
First Well's Market Value$_{j,t}$			0.202***	22.39
			(0.060)	
Peers' Wells' Value$_{j,t}$			0.058***	5.94
			(0.014)	
Oil-to-Gas Ratio$_{j}$			0.350***	41.92
			(0.122)	
Drilling Cost$_{j,t}$			-0.051**	-4.96
			(0.024)	
Futures Price$_{t}$			0.009***	0.86
			(0.003)	
Implied Volatility$_{t}$			-0.035***	-3.41
			(0.007)	
10-Year Risk Free Rate$_{t}$			0.135**	14.44
			(0.060)	
Cost of Equity$_{t}$			-0.704**	-50.56
			(0.282)	
Chi^2 (Same Resource—Different Resource)	8.21***		15.49***	
(p-Value)	(0.004)		(0.000)	
County Strata	Yes		Yes	
$Pseudo-Loglikelihood$	-17,330		-17,107	
Wald Chi^2	474		1,047	
Observations	540,765		540,765	

Table 7: Two-Stage (Linear-Cox) Instrumental Variables Results. This table reports the results of two-stage instrumental variable 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. Panel A displays the linear first-stage results. The dependent variable 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. The main independent variable of interest is *Landownership Fragmentation*, which is equal to the natural log of the number of landowners per available section located within 3 miles of the section of interest. Panel B reports the second-stage instrumented Cox regression results. The main independent variable is *Instrumented Unexercised Investment Opportunities (Peers)*, which is equal to the fitted values from the linear first-stage regressions in Panel A. 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. Finally, data on historical landownership use in the first-stage regressions in Panel A are from the Bureau of Land Management (BLM). All variables are defined in Table A1. Robust standard errors, clustered at the county level, are reported in parentheses. In Panel B, the clustered standard errors are generated using a bootstrapping procedure with 500 iterations. *,**, and *** denote significance at the 10%, 5%, and 1% level, respectively.

Panel A: First Stage Results

Dependent variable =	Unexercised Investment Opportunities (Peers)$_{j,t}$		
	(1)	(2)	(3)
Landowners Fragmentation$_{j,t}$	0.011***	0.011***	0.011***
	(0.003)	(0.003)	(0.003)
Cumulative Number of Well's Drilled$_{j,t}$	0.172***	0.163***	0.167***
	(0.023)	(0.023)	(0.024)
Unexercised Investment Opportunities (Own)$_{j,t}$	-0.349***	-0.358***	-0.363***
	(0.022)	(0.022)	(0.021)
Portfolio Concentration$_{i,k,t}$	-1.202***	-1.351***	-1.362***
	(0.449)	(0.456)	(0.444)
Mean Distance Between Options$_{i,t}$	-0.363***	-0.396***	-0.402***
	(0.101)	(0.105)	(0.102)
Firm Skill Level$_{i,t}$	0.231*	0.082	0.124
	(0.139)	(0.129)	(0.126)
First Well's Market Value$_{j,t}$		0.012	-0.018
		(0.058)	(0.063)
Peers' Wells' Value$_{j,t}$		0.143***	0.141***
		(0.019)	(0.019)
Oil-to-Gas Ratio$_{j}$		-0.151	-0.138
		(0.415)	(0.401)
Drilling Cost$_{j,t}$		0.050*	0.034
		(0.030)	(0.028)
Futures Price$_{t}$			0.011***
			(0.004)
Implied Volatility$_{t}$			-0.005
			(0.006)
10-Year Risk Free Rate$_{t}$			-0.236***
			(0.084)
Cost of Equity$_{t}$			-0.272
			(0.336)
County FE	Yes	Yes	Yes
KP F-statistic	10.15	10.86	11.40
Observations	415,170	415,170	415,170
R^2	0.47	0.48	0.48

(*Continued*)

Table 7—*Continued*

Panel B: Second Stage Results

	Hazard Model for Project Exercise					
	(1)		(2)		(3)	
	Estimates	HI(%)	Estimates	HI(%)	Estimates	HI(%)
Instrumented Unexercised Investment Opportunities (Peers)$_{j,t}$	-0.271*	-23.76	-0.238**	-21.14	-0.263**	-23.14
	(0.150)		(0.121)		(0.123)	
Cumulative Number of Well's Drilled$_{j,t}$	0.094***	9.87	0.081***	8.45	0.091***	9.51
	(0.027)		(0.023)		(0.024)	
Unexercised Investment Opportunities (Own)$_{j,t}$	-0.123**	-11.60	-0.117**	-11.05	-0.139***	-12.98
	(0.054)		(0.046)		(0.048)	
Portfolio Concentration$_{i,k,t}$	-0.121	-11.43	-0.195	-17.70	-0.289	-25.09
	(0.239)		(0.238)		(0.209)	
Mean Distance Between Options$_{i,t}$	-0.168***	-15.49	-0.172***	-15.79	-0.194***	-17.64
	(0.058)		(0.053)		(0.048)	
Firm Skill Level$_{i,t}$	0.080	8.28	-0.163	-15.03	-0.086	-8.20
	(0.088)		(0.110)		(0.116)	
First Well's Market Value$_{j,t}$			0.244***	27.62	0.216***	24.12
			(0.076)		(0.069)	
Peers' Wells' Value$_{j,t}$			0.087***	9.06	0.086***	9.01
			(0.021)		(0.021)	
Oil-to-Gas Ratio$_{j}$			0.297*	34.62	0.359***	43.22
			(0.155)		(0.138)	
Drilling Cost$_{j,t}$			-0.050	-4.91	-0.042	-4.14
			(0.031)		(0.029)	
Futures Price$_{t}$					0.013***	1.36
					(0.003)	
Implied Volatility$_{t}$					-0.033***	-3.27
					(0.008)	
10-Year Risk Free Rate$_{t}$					0.042	4.25
					(0.082)	
Cost of Equity$_{t}$					-0.963**	-61.84
					(0.453)	
County Strata	Yes		Yes		Yes	
$Pseudo - Loglikelihood$	-13,658		-13,575		-13,475	
Wald Chi^2	93		122		202	
Observations	415,170		415,170		415,170	

Table 8: Direction of Bias and Internal Validity of the Instrumental Variable. This table reports the results of linear regression models that investigate the internal validity of our instrumental variable (Panel A), as well as the direction of the omitted varaiables bias from our reduced form Cox models (Panel B). The sample includes section observations for exercised options over the period of 2005 through 2020. In both panels, the dependent variable is the natural log of the market value of a section's first well. In Panel A, the independent variable of interest is *Landowners Fragmentation*, which measures the natural log of of the number of landowners per available section located within 3 miles of the section of interest. In Panel B, the independent variable 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. The control variables used in Model (2) of both panels are the same as those in Model (3) of Table 2. 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. Finally, data on historical landownership use in the regressions in Panel A are from the Bureau of Land Management (BLM). All variables are defined in Table A1. Robust standard errors, clustered at the county level, are reported in parentheses. *,**, and *** denote significance at the 10%, 5%, and 1% level, respectively.

Panel A: Internal Validity		
Dependent variable =	log(First Well's Market Value$_j$)	
	(1)	(2)
Historical Landowners Fragmentation$_{j,t}$	-0.000	-0.001
	(0.001)	(0.001)
Controls	No	Yes
County FE	Yes	Yes
Observations	6,956	6,956
R^2	0.30	0.34
Panel B: Direction of Bias		
Dependent variable =	log(First Well's Market Value$_j$)	
	(1)	(2)
Unexercised Investment Opportunities (Peers)$_j$	0.030***	0.014
	(0.007)	(0.009)
Controls	No	Yes
County FE	Yes	Yes
Observations	6,956	6,956
R^2	0.31	0.34

Table 9: Option Ownership Concentration and Total Regional Investment. This table reports the results of cross-sectional linear regression models in which the dependent variable is total investment in a region by the end of our sample period. The main independent variable of interest is *Options Ownership Concentration*, which is akin to an option-ownership HHI. 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. 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 =	Total Regional Investment$_k$		
	(1)	(2)	(3)
Options Ownership Concentration$_k$	2.025***	1.751***	1.741***
	(0.253)	(0.239)	(0.370)
Cumulative Number of Options Available$_k$	0.620***	0.636***	0.649***
	(0.030)	(0.029)	(0.031)
Average Well's Market Value$_k$	-0.213***	-0.014	-0.035
	(0.070)	(0.089)	(0.130)
Average Drilling Cost$_k$	0.001	-0.059	-0.059
	(0.045)	(0.048)	(0.050)
Region Cohort-Year FE	Yes	Yes	No
County FE	No	Yes	No
Region Cohort-Year × County FE	No	No	Yes
Observations	1,058	1,044	772
R^2	0.78	0.82	0.85

Table 10: Peer Options and *Valuable* Project Exercise. 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). This table also further investigates Chamley and Gale's (1994) Proposition 4 that the anticipation of information spillover induces delays even for projects that would be profitable to exercise immediately. Thus, the sample includes section-month observations over the period of 2005 through 2020, but only for options located in regions in which the market value of the average drilled peer well is above the sample median. This leaves us with a reduced sample of 270,383 option-month observations covering 6,418 unique 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 Table A1. 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**	-2.86	-0.028**	-2.77	-0.031**	-3.05
	(0.013)		(0.014)		(0.013)	
Cumulative Number of Well's Drilled$_{j,t}$	0.047***	4.80	0.046***	4.68	0.047***	4.80
	(0.006)		(0.006)		(0.006)	
Unexercised Investment Opportunities (Own)$_{j,t}$	-0.030**	-2.95	-0.030**	-2.99	-0.038***	-3.76
	(0.012)		(0.012)		(0.012)	
Portfolio Concentration$_{i,k,t}$	0.072	7.50	0.131	14.01	0.105	11.05
	(0.213)		(0.191)		(0.185)	
Mean Distance Between Options$_{i,t}$	-0.112***	-10.56	-0.121***	-11.40	-0.124***	-11.64
	(0.041)		(0.038)		(0.036)	
Firm Skill Level$_{i,t}$	-0.295***	-25.53	-0.485***	-38.41	-0.438***	-35.47
	(0.108)		(0.115)		(0.119)	
First Well's Market Value$_{j,t}$			0.173***	18.90	0.176***	19.28
			(0.061)		(0.060)	
Peers' Wells' Value$_{j,t}$			0.775***	117.00	0.668***	95.12
			(0.104)		(0.101)	
Oil-to-Gas Ratio$_{j}$			0.372***	45.00	0.374***	45.32
			(0.130)		(0.116)	
Drilling Cost$_{j,t}$			-0.070**	-6.80	-0.069**	-6.71
			(0.029)		(0.030)	
Futures Price$_{t}$					0.007***	0.68
					(0.002)	
Implied Volatility$_{t}$					-0.036***	-3.55
					(0.009)	
10-Year Risk Free Rate$_{t}$					0.019	1.93
					(0.086)	
Cost of Equity$_{t}$					-0.732	-51.89
					(0.463)	
County Strata	Yes		Yes		Yes	
$Pseudo-Loglikelihood$	-11,041		-10,931		-10,882	
Wald Chi^2	269		782		1,178	
Observations	270,383		270,383		270,383	

Table 11: Falsification Test. 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 *Falsified Unexercised Investment Opportunities (Peers)*, which is equal to the number of real options held by a firm's peers and located between 10 and 13 miles from 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 Table A1. 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(%)
Falsified Unexercised Investment Opportunities (Peers)$_{j,t}$	-0.002	-0.20	-0.003	-0.31	-0.001	-0.07
	(0.003)		(0.003)		(0.002)	
Cumulative Number of Well's Drilled$_{j,t}$	0.050***	5.11	0.045***	4.65	0.047***	4.83
	(0.003)		(0.004)		(0.003)	
Unexercised Investment Opportunities (Own)$_{j,t}$	-0.028***	-2.77	-0.034***	-3.36	-0.041***	-4.02
	(0.009)		(0.009)		(0.008)	
Portfolio Concentration$_{i,k,t}$	0.220	24.60	0.158	17.09	0.124	13.18
	(0.181)		(0.175)		(0.166)	
Mean Distance Between Options$_{i,t}$	-0.052	-5.09	-0.058*	-5.60	-0.063*	-6.08
	(0.037)		(0.035)		(0.033)	
Firm Skill Level$_{i,t}$	-0.029	-2.83	-0.226***	-20.25	-0.185**	-16.87
	(0.059)		(0.085)		(0.085)	
First Well's Market Value$_{j,t}$			0.221***	24.76	0.199***	22.04
			(0.067)		(0.061)	
Peers' Wells' Value$_{j,t}$			0.058***	5.93	0.053***	5.48
			(0.015)		(0.014)	
Oil-to-Gas Ratio$_j$			0.324**	38.24	0.377***	45.75
			(0.135)		(0.133)	
Drilling Cost$_{j,t}$			-0.067***	-6.48	-0.051**	-4.95
			(0.026)		(0.023)	
Futures Price$_t$					0.008***	0.82
					(0.003)	
Implied Volatility$_t$					-0.034***	-3.37
					(0.007)	
10-Year Risk Free Rate$_t$					0.146**	15.67
					(0.061)	
Cost of Equity$_t$					-0.680**	-49.33
					(0.284)	
County Strata	Yes		Yes		Yes	
$Pseudo - Loglikelihood$	-17,341		-17,239		-17,125	
Wald Chi^2	458		485		1,130	
Observations	540,765		540,765		540,765	

Table 12: 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 firms 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. 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)	
Peers Distance Definition =	2 Miles		3 Miles		4 Miles	
	Estimates	HI(%)	Estimates	HI(%)	Estimates	HI(%)
Unexercised Investment Opportunities (Peers)$_{j,t}$	-0.065***	-6.29	-0.037***	-3.66	-0.016***	-1.54
	(0.016)		(0.010)		(0.005)	
Cumulative Number of Well's Drilled$_{j,t}$	0.050***	5.12	0.052***	5.29	0.050***	5.14
	(0.004)		(0.004)		(0.004)	
Unexercised Investment Opportunities (Own)$_{j,t}$	-0.051***	-4.95	-0.053***	-5.17	-0.049***	-4.76
	(0.010)		(0.010)		(0.009)	
Portfolio Concentration$_{i,k,t}$	0.109	11.51	0.089	9.35	0.101	10.58
	(0.162)		(0.162)		(0.163)	
Mean Distance Between Options$_{i,t}$	-0.066*	-6.41	-0.072**	-6.91	-0.069**	-6.66
	(0.034)		(0.034)		(0.034)	
Firm Skill Level$_{i,t}$	-0.184**	-16.77	-0.183**	-16.72	-0.184**	-16.78
	(0.083)		(0.083)		(0.084)	
First Well's Market Value$_{j,t}$	0.201***	22.21	0.202***	22.35	0.201***	22.32
	(0.061)		(0.060)		(0.061)	
Peers' Wells' Value$_{j,t}$	0.057***	5.85	0.058***	5.96	0.056***	5.80
	(0.014)		(0.014)		(0.014)	
Oil-to-Gas Ratio$_j$	0.363***	43.79	0.360***	43.27	0.362***	43.69
	(0.125)		(0.124)		(0.127)	
Drilling Cost$_{j,t}$	-0.052**	-5.06	-0.051**	-5.00	-0.051**	-4.95
	(0.024)		(0.024)		(0.024)	
Futures Price$_t$	0.008***	0.85	0.008***	0.85	0.008***	0.84
	(0.003)		(0.003)		(0.003)	
Implied Volatility$_t$	-0.035***	-3.40	-0.035***	-3.41	-0.035***	-3.40
	(0.007)		(0.007)		(0.007)	
10-Year Risk Free Rate$_t$	0.138**	14.82	0.135**	14.44	0.139**	14.91
	(0.060)		(0.060)		(0.060)	
Cost of Equity$_t$	-0.694**	-50.02	-0.700**	-50.36	-0.691**	-49.89
	(0.278)		(0.282)		(0.281)	
County Strata	Yes		Yes		Yes	
$Pseudo-Loglikelihood$	-17,109		-17,108		-17,118	
Wald Chi^2	1,094		1,024		997	
Observations	540,765		540,765		540,765	

Appendix A

Subscript t indicates a month-year pair, i indicates a specific firm, k identifies a county, and j denotes a specific option.

Table A1: Variable Definitions

Variable	Definition
10-Year Risk Free Rate$_t$	The 10-year risk free rate measured at the monthly frequency, obtained from https://fred.stlouisfed.org/series/GS10.
Cost of Equity$_t$	The oil and gas industry beta, measured on month-year t over a three year horizon. The oil and gas industry monthly return is taken from Kenneth French 49 industry dataset https://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html, and the risk free rate is taken from Fama French data available on WRDS.
Cumulative Number of Well's Drilled$_{j,t}$	Total number of wells drilled in the 3 miles surrounding option j during month-year t.
Drilling Cost$_{j,t}$	The natural logarithm of the estimated well's drilling cost for the first well drilled on option j using the per-foot cost observed during month-year t. To obtain the drilling cost, we multiply the well's lateral length with the per-foot cost of drilling wells, updated at the monthly frequency. The per-foot cost of drilling is manually collected from regulatory fillings. See Décaire et al. (2020) for more details.
Falsified Unexercised Investment Opportunities (Peers)$_{j,t}$	The number of options held by any of a firm's peers located within 10 and 13 miles from option j during month-year t.
First Well's Market Value$_{j,t}$	Natural logarithm of the market value for first year of production of the first well drilled on option j during month-year t. We obtain the market value by multiplying the well's production in the first year with the future prices.
Firm Skill Level$_{j,t}$	Natural logarithm of the average market value for first year of production of all the wells drilled by firm i up to month-year t. We obtain the market value by multiplying the well's production in the first year with the future prices.
Futures Price$_t$	18-month Oil futures prices, measured for each month-year t.
Implied Volatility$_t$	18-month oil futures implied volatility, measured for each month-year t.
I(Peers' Options ≤ 3)	An indicator variable equal to 1 if there are at least 3 unexercised options that are held by any of a firm's peers, and 0 otherwise.

Landowners Fragmentation$_j$	Total number of historical landowner in the option's 3 miles surrounding region, measured using the Bureau of Land Management. Source:https://glorecords.blm.gov/BulkData/default.aspx.
Mean Distance Between Options$_{j,t}$	The natural log of average distance between all the options held be a firm i on month-year t.
Oil-to-Gas Ratio$_j$	First year production of oil divided by the well's first year barrel of oil equivalent (BOE). To transpose natural gas into barrel of oil equivalent, we divide the quantity of natural gas produced in the first year by 6 (https://www.eia.gov/energyexplained/units-and-calculators/).
Peers' Wells' Mkt. Value$_{j,t}$	Natural logarithm of the average first year production value for the peers' wells drilled within 3 miles of option j during month-year t.
Portfolio Concentration$_{i,k,t}$	Proportion of a firm i total available options, that are located in the option's county k during month-year t.
Scaled Unexercised Investment Opportunities (High-Skill Peers)$_{j,t}$	The number of options held by any of a firm's high skilled peers located within 3 miles from the option, divided by the standard deviation of the variable *Unexercised Investment Opportunities (High-Skill Peers)*$_{j,t}$. *High -kill Peers* denotes peers for which the average production value is greater or equal than the sample median during month-year t.
Scaled Unexercised Investment Opportunities (Low-Skill Peers)$_{j,t}$	The number of options held by any of a firm's low skilled peers located within 3 miles from the option, divided by the standard deviation of the variable *Unexercised Investment Opportunities (Low-Skill Peers)*$_{j,t}$. *Low-Skill Peers* denotes peers for which the average production value is less than the sample median at time t.
Township's Contemporaneous Landowners Fragmentation$_m$	Total number of historical landowner in township m, measured using the DrillingInfo leasing data.
Township's Historical Landowners Fragmentation$_m$	Total number of historical landowner in township m, measured using the Bureau of Land Management historical patent data. Source:https://glorecords.blm.gov/BulkData/default.aspx.
Unexercised Investment Opportunities (Own)$_{j,t}$	The number of options held by the firm located within 3 miles from option j during month-year t.
Unexercised Investment Opportunities (Peers)$_{j,t}$	The number of options held by any of a firm's peers located within 3 miles from option j during month-year t.
Unexercised Investment Opportunities (Peers)$^2_{j,t}$	The number of options held by any of a firm's peers located within 3 miles from option j during month-year t.

Well Lateral Length$_j$ (1,000 ft.)	The lateral length of option j first horizontal well, in thousands of feet.

Appendix B

To obtain a measure of an exercised option's net present value (NPV), we follow the strategy documented in Décaire and Sosyura (2021). That is, we rely on a petroleum production model called the Arp model to measure the average depletion rate of the wells in our sample (Fetkovich et al., 1996). Then, using this model, one can approximate the net discounted value of an oil and gas well by measuring

$$\text{Projected NPV} = \int_0^{\infty} Prod_0(1 - FC - R)e^{-(d+r)t}dt - Cost, \tag{5}$$

where $Prod_0$ corresponds to the value of the production in the first year, FC is the flexible cost associated with the overall operations of the wells (in proportion to the production), R denotes the royalty payments paid to landowners, d denotes the depletion rate of production (i.e., the speed at which production declines over time), r is the discount rate used to evaluate the well, t corresponds to the number of months since the well was drilled, and $Cost$ is the capital cost associated with drilling the well. We use the depletion rate estimated in Décaire and Sosyura (2021) for horizontal wells (0.42), and define the discount rate as the CAPM rate of return for the oil and gas industry. We use the 10 year treasure yield for our measure of the risk free rate, available from the St. Louis Federal Reserve Bank, the equity premium estimate from Fama and French (2002), and we estimate the oil and gas industry beta at the monthly frequency on a three year horizon using Kenneth French industry returns. FC is set to 20% following the methodology of Décaire et al. (2020), and the royalty rate is set to 18.75% as it corresponds to the median value for royalty rates in both Oklahoma and Louisiana for the sample period. Importantly, 78% of all leases signed in those states for the sample period have a royalty rate included in the 18.75% $\pm$ 2% range. Finally, to obtain an estimate of the NPV, we assume that wells will produce infinitely. This assumption is implemented without loss of generality, as most existing wells (more than 70%, see Figure 5) have a production life exceeding 15 years. Then, when using a depletion rate of 42%, and a CAPM discount rate of 7.46%, the discounted value of cash flows beyond that point in time is infinitesimally small. Then, we obtain our NPV estimate for any given drilled well by computing the following:

$$\text{Projected NPV} = \frac{Prod_0(1 - 18.75\% - 0.2)}{d + r} - Cost \tag{6}$$

Internet Appendix
for
Waiting on a Friend: Strategic Learning and Corporate Investment

PAUL H. DÉCAIRE* and MICHAEL D. WITTRY†

This Internet Appendix reports results that are mentioned but not tabulated in the main paper. We report 6 tables, as outlined below:

1. Table IA.1: Project Exercise Value Gain From Waiting

   Reference in the main paper: "In our sample, this cost appears to exceed any observed benefits of waiting. That is, Internet Appendix Table IA.1 Model (2) suggests that each additional month an option is held before exercising is associated with an increase of at most 0.024% in project value when the infill well is ultimately drilled." (Section 5)

2. Table IA.2: Indicator Variable Approach to Measuring Potential Information Spillover

   Reference in the main paper: "However, our results are not sensitive to this modeling decision. Section 8 discusses results that use an indicator variable equal to 1 for projects with any positive number of peer options. These results are contained in the Internet Appendix (Table IA.2) and are quantitatively and qualitatively similar to our main results below." (Section 5.1)

   Reference in the main paper: "Finally, the Internet Appendix reports tables from a series of empirical specifications that show our results are robust to other econometric modeling techniques. In particular, the inference from the following models remain qualitatively similar:
   (i) Indicator variable approach to measuring potential information spillover (Table IA.1)" (Section 8)

3. Table IA.3: Landownership Fragmentation Through Time

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Reference in the main paper: “Furthermore, Internet Appendix Table IA.3 presents regressions that suggest the number of historical landowners can explain as much as 45% of the variation in contemporaneous landowners within a county.” (Section 6)

4. Table IA.4: Robustness to the Reduced Sample with Data on Historical Landownership

   Reference in the main paper: “Finally, the Internet Appendix reports tables from a series of empirical specifications that show our results are robust to other econometric modeling techniques. In particular, the inference from the following models remain qualitatively similar:
   (ii) Results from the reduced sample with data on historical landownership (Table IA.4)” (Section 8)

5. Table IA.5: Alternative Model Specifications

   Reference in the main paper: “Finally, the Internet Appendix reports tables from a series of empirical specifications that show our results are robust to other econometric modeling techniques. In particular, the inference from the following models remain qualitatively similar:
   (iii) Reduced form linear regression models (Table IA.5)
   (iv) Reduced form probit regression models (Table IA.5)
   (v) Two-stage least squares (linear-linear) regression models (Table IA.5)
   (vi) Two-stage least squares (linear-probit) regression models (Table IA.5)” (Section 8)

6. Table IA.6: Cox Models with Standard Errors Clustered at the Firm Level

   Reference in the main paper: “Finally, the Internet Appendix reports tables from a series of empirical specifications that show our results are robust to other econometric modeling techniques. In particular, the inference from the following models remain qualitatively similar:
   (vii) Models that cluster standard errors by firm rather than county (Table IA.6)” (Section 8)

Table IA.1: Project Exercise Value Gain From Waiting. This table reports the results of linear regression models that investigate the potential benefits of delay project exercise. The sample includes option-level observations for exercised options over the period of 2005 through 2020. The dependent variable is the natural log of the market value of a section's second well, while the independent variable of interest is *Months Held Before Exercising*, which measures the number of months a firm holds an option before ultimately exercising it. The control variables used in Model (2) of both panels are the same as those in Model (3) of Table 2. 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.

Dependent variable =	log(Second Well's Market Value$_{j,t}$)	
	(1)	(2)
Months Held Before Exercising	-0.0010	0.0036*
	(0.0018)	(0.0020)
Controls	No	Yes
County FE	Yes	Yes
Observations	3,474	3,474
R^2	0.36	0.48

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(Peers' Options* ≥ 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(Peers' Options $\geq$ 1)	-0.115**	-10.82	-0.227***	-20.31	-0.205***	-18.50
	(0.052)		(0.054)		(0.052)	
Cumulative Number of Well's Drilled$_{j,t}$	0.050***	5.12	0.046***	4.69	0.049***	4.97
	(0.003)		(0.004)		(0.003)	
Unexercised Investment Opportunities (Own)$_{j,t}$	-0.027***	-2.70	-0.034***	-3.36	-0.043***	-4.24
	(0.009)		(0.008)		(0.008)	
Portfolio Concentration$_{i,k,t}$	0.230	25.83	0.169	18.42	0.127	13.53
	(0.179)		(0.172)		(0.164)	
Mean Distance Between Options$_{i,t}$	-0.048	-4.65	-0.052	-5.06	-0.062*	-5.99
	(0.037)		(0.035)		(0.034)	
Firm Skill Level$_{i,t}$	-0.035	-3.48	-0.243***	-21.59	-0.191**	-17.39
	(0.057)		(0.082)		(0.083)	
First Well's Market Value$_{j,t}$			0.219***	24.51	0.199***	21.99
			(0.067)		(0.061)	
Peers' Wells' Value$_{j,t}$			0.065***	6.70	0.060***	6.23
			(0.015)		(0.014)	
Oil-to-Gas Ratio$_j$			0.312**	36.61	0.369***	44.61
			(0.134)		(0.131)	
Drilling Cost$_{j,t}$			-0.068**	-6.58	-0.050**	-4.91
			(0.027)		(0.024)	
Futures Price$_t$					0.008***	0.83
					(0.003)	
Implied Volatility$_t$					-0.034***	-3.36
					(0.007)	
10-Year Risk Free Rate$_t$					0.142**	15.31
					(0.062)	
Cost of Equity$_t$					-0.672**	-48.93
					(0.277)	
County Strata	Yes		Yes		Yes	
$Pseudo-Loglikelihood$	-17,340		-17,233		-17,118	
Wald Chi^2	377		546		1,117	
Observations	540,765		540,765		540,765	

Table IA.3: 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 an gas leases are from DrillingInfo, and data on historical landownership are from the Bureau of Land Management (BLM). 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$_k$	
	(1)	(2)
Historical Landowners$_k$	2.299***	0.875**
	(0.301)	(0.394)
County FE	No	Yes
Observations	2,024	2,011
R^2	0.11	0.45

Table IA.4: 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**	-2.86	-0.034**	-3.35	-0.036***	-3.56
	(0.013)		(0.013)		(0.013)	
Cumulative Number of Well's Drilled$_{j,t}$	0.051***	5.24	0.047***	4.76	0.051***	5.26
	(0.005)		(0.005)		(0.005)	
Unexercised Investment Opportunities (Own)$_{j,t}$	-0.041***	-4.00	-0.046***	-4.52	-0.058***	-5.68
	(0.013)		(0.013)		(0.012)	
Portfolio Concentration$_{i,k,t}$	0.248	28.08	0.149	16.06	0.071	7.35
	(0.212)		(0.197)		(0.184)	
Mean Distance Between Options$_{i,t}$	-0.055	-5.39	-0.068	-6.58	-0.086**	-8.20
	(0.045)		(0.042)		(0.039)	
Firm Skill Level$_{i,t}$	0.020	2.04	-0.185*	-16.89	-0.120	-11.34
	(0.067)		(0.104)		(0.108)	
First Well's Market Value$_{j,t}$			0.242***	27.33	0.221***	24.75
			(0.084)		(0.076)	
Peers' Wells' Value$_{j,t}$			0.057***	5.89	0.054***	5.58
			(0.017)		(0.015)	
Oil-to-Gas Ratio$_j$			0.307**	35.91	0.358***	43.03
			(0.140)		(0.135)	
Drilling Cost$_{j,t}$			-0.059**	-5.75	-0.050*	-4.84
			(0.028)		(0.026)	
Futures Price$_t$					0.011***	1.10
					(0.003)	
Implied Volatility$_t$					-0.032***	-3.16
					(0.008)	
10-Year Risk Free Rate$_t$					0.094	9.85
					(0.074)	
Cost of Equity$_t$					-0.900**	-59.32
					(0.419)	
County Strata	Yes		Yes		Yes	
$Pseudo-Loglikelihood$	-13,656		-13,570		-13,470	
Wald Chi^2	262		337		834	
Observations	415,170		415,170		415,170	

Table IA.5: 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 =	Project Exercise			
Model =	Linear		Probit	
	(1)	(2)	(3)	(4)
	Reduced Form	IV	Reduced Form	IV
Unexercised Investment Opportunities (Peers)$_{j,t}$	-0.0002***	-0.0008	-0.0116**	-0.0792**
	(0.0001)	(0.0006)	(0.0052)	(0.0352)
Cumulative Number of Well's Drilled$_{j,t}$	0.0002***	0.0003***	0.0116***	0.0237***
	(0.0000)	(0.0001)	(0.0014)	(0.0068)
Unexercised Investment Opportunities (Own)$_{j,t}$	-0.0004***	-0.0006***	-0.0224***	-0.0500***
	(0.0001)	(0.0002)	(0.0046)	(0.0136)
Portfolio Concentration$_{i,k,t}$	0.0012	0.0008	0.0544	-0.0335
	(0.0014)	(0.0015)	(0.0648)	(0.0744)
Mean Distance Between Options$_{i,t}$	-0.0006*	-0.0008**	-0.0352**	-0.0625***
	(0.0003)	(0.0004)	(0.0145)	(0.0192)
Firm Skill Level$_{i,t}$	-0.0016***	-0.0011	-0.1141***	-0.0585
	(0.0006)	(0.0008)	(0.0388)	(0.0457)
First Well's Market Value$_{j,t}$	0.0024***	0.0024***	0.1648***	0.1531***
	(0.0003)	(0.0005)	(0.0237)	(0.0293)
Peers' Wells' Value$_{j,t}$	0.0004***	0.0004***	0.0286***	0.0350***
	(0.0001)	(0.0001)	(0.0065)	(0.0082)
Oil-to-Gas Ratio$_j$	0.0040***	0.0038***	0.2407***	0.2178***
	(0.0011)	(0.0011)	(0.0637)	(0.0596)
Drilling Cost$_{j,t}$	-0.0002	-0.0001	-0.0158*	-0.0075
	(0.0001)	(0.0001)	(0.0092)	(0.0089)
Futures Price$_t$	0.0001***	0.0002***	0.0079***	0.0103***
	(0.0000)	(0.0000)	(0.0015)	(0.0018)
Implied Volatility$_t$	-0.0002**	-0.0002**	-0.0160***	-0.0167***
	(0.0001)	(0.0001)	(0.0032)	(0.0035)
10-Year Risk Free Rate$_t$	0.0028***	0.0011	0.1348***	0.0370
	(0.0010)	(0.0009)	(0.0462)	(0.0447)
Cost of Equity$_t$	-0.0087**	-0.0111**	-0.7077***	-0.8419***
	(0.0035)	(0.0043)	(0.1599)	(0.2208)
County FE	Yes	Yes	Yes	Yes
Observations	540,765	415,170	530,251	405,915

Table IA.6: 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***	-2.93	-0.037***	-3.59	-0.037***	-3.66
	(0.008)		(0.008)		(0.008)	
Cumulative Number of Well's Drilled$_{j,t}$	0.053***	5.41	0.048***	4.97	0.052***	5.29
	(0.004)		(0.003)		(0.003)	
Unexercised Investment Opportunities (Own)$_{j,t}$	-0.036***	-3.51	-0.043***	-4.22	-0.053***	-5.17
	(0.010)		(0.010)		(0.010)	
Portfolio Concentration$_{i,k,t}$	0.199	22.04	0.131	14.00	0.089	9.35
	(0.154)		(0.163)		(0.154)	
Mean Distance Between Options$_{i,t}$	-0.056	-5.40	-0.061	-5.96	-0.072	-6.91
	(0.044)		(0.044)		(0.044)	
Firm Skill Level$_{i,t}$	-0.028	-2.79	-0.235**	-20.91	-0.183*	-16.72
	(0.055)		(0.102)		(0.104)	
First Well's Market Value$_{j,t}$			0.222***	24.89	0.202***	22.35
			(0.081)		(0.075)	
Peers' Wells' Value$_{j,t}$			0.061***	6.33	0.058***	5.96
			(0.011)		(0.011)	
Oil-to-Gas Ratio$_j$			0.306***	35.82	0.360***	43.27
			(0.114)		(0.122)	
Drilling Cost$_{j,t}$			-0.068***	-6.60	-0.051***	-5.00
			(0.020)		(0.020)	
Futures Price$_t$					0.008***	0.85
					(0.002)	
Implied Volatility$_t$					-0.035***	-3.41
					(0.005)	
10-Year Risk Free Rate$_t$					0.135**	14.44
					(0.056)	
Cost of Equity$_t$					-0.700***	-50.36
					(0.196)	
County Strata	Yes		Yes		Yes	
$Pseudo - Loglikelihood$	-17,331		-17,224		-17,108	
Wald Chi^2	269		374		614	
Observations	540,765		540,765		540,765	