The Effect of Repeated Interaction on Contract Choice: Evidence from Offshore Drilling

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We argue that repeated interaction and high-powered formal contracts can be either substitutes or complements, depending on the relative impact of repeated interaction on incentive problems and contracting costs. In the offshore drilling industry, we find that oil and gas companies are less likely to choose fixed-price contracts as the frequency of their interaction with a driller increases. This supports the conclusion that repeated interaction and high-powered formal contracts are substitutes in this setting, indicating that repeated interaction reduces incentive problems more than contracting costs. In addition, we find that using instrumental variables to account for the endogenous matching of drillers to projects strengthens our results.

1. Introduction

Oil and gas companies contract with independent drillers under two very different types of contracts, known as day-rate and turnkey contracts. These are roughly analogous, respectively, to cost-plus and fixed-price contracts used in construction, military procurement, and many kinds of professional services, including consulting and software development. In complex contracting environments, the choice between these two types of contracts may present the buyer with a dilemma. On the one hand, writing a fixed-price contract requires carefully enumerating many contingencies and detailing the project specifications ex ante, which is costly. In addition, this creates inflexibility and raises the specter of holdup and/or costly renegotiation once the project is under way, should desired project

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We thank George Baker, Oliver Hart, Mark Israel, Dale Jorgenson, Paul Oyer, Steve Tadelis, Oliver Williamson, two anonymous referees, and seminar participants at Carnegie Mellon, Harvard, Stanford, London Business School, MIT, Michigan, Northwestern, University of Southern California, Wharton, Arizona, Toronto, Michigan State, and the 2002 AEA meetings for helpful comments.

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The Journal of Law, Economics, & Organization, Vol. 20, No. 1,
 DOI: 10.1093/jleo/ewh031

specifications change. On the other hand, a cost-plus contract is simpler to write and gives the buyer more flexibility in altering the specifications as the project proceeds; however, this flexibility comes at the cost of introducing a moral hazard problem, as the agent may bill the principal for excessive materials and labor.

The choice becomes even more complicated in the context of repeated contracting. For example, having completed a bathroom renovation, does the homeowner negotiating with the same contractor for kitchen remodeling lean toward one type of contract or the other? Does the trust established through repeated contracting more dramatically assuage fears of holdup in renegotiation (making a fixed-price contract more attractive) or skepticism about the legitimacy of the cost-plus charges (making a cost-plus contract more attractive)? Formally, are repeated contracting and high-powered (fixed-price) formal contracts substitutes or complements? We argue that the answer is in general ambiguous. Empirically we examine the effect of repeated interaction on the choice of contract type in the offshore drilling industry and conclude that, in this particular context, the two are substitutes. As a preview of our results, consider these striking figures: high-powered turnkey contracts govern 28% of projects between parties who have not worked together before, but only 15% of repeat contracts.

Two articles have highlighted the importance of the trade-off between moral hazard and contracting/recontracting costs in procurement and construction contracts without considering the effect of repeated interaction. Crocker and Reynolds (1993) emphasize that the optimal contract features a degree of completeness that strikes an appropriate balance between these costs and benefits. In a more formal model, Bajari and Tadelis (2001) show why contract completeness and strong incentives go together and suggest a number of reasons why optimal contracts for various projects may tend to fall into the dichotomous categories of fixed-price and cost-plus as they do in a wide range of industries.[1]

We extend this literature by empirically exploring the impact of repeated interaction on the choice of contract form.[2] We argue that whether repeated interaction makes high-powered (fixed-price or turnkey) formal

1. Others have argued that other considerations beyond the realm of standard contract theory play important roles in contract choice. For example, Oyer (2002) argues that compensation plans tied to stock performance serve to match compensation to outside offers over time rather than to provide incentives, and Lafontaine and Masten (2002) argue that trucking contracts are structured to economize on price setting across heterogeneous projects rather than to induce effort. While such alternative explanations may also apply to this industry, we focus here on the considerations suggested by the literature on moral hazard and transaction costs, since these considerations seem the most likely to be mitigated through repeated contracting.

2. A large literature suggests that repeated interaction may affect the structure of economic relationships by allowing implicit contracts to be sustained [Klein and Leffler (1981), Williamson (1985), Bull (1987), Baker, Gibbons, and Murphy (1994), and Klein (1996)].

contracts more or less attractive relative to low-powered (cost-plus or day-rate) contracts depends on how it affects *both* incentive problems and contracting costs.[3] If repeated interaction helps sustain effort levels sufficiently close to those provided by high-powered formal contracts but does not lead to much savings in contracting, it tips the trade-off in favor of low-powered (cost-plus) contracts, which have lower contracting costs. In contrast, if repeated interaction reduces contracting costs but does not provide significant improvements in incentives, it tips the trade-off toward higher-powered formal contracts.

Two empirical articles provide some evidence that repeated interaction and strong formal contracts might be substitutes. Gulati (1995) studies governance structures in interfirm alliances and finds that repeated alliances between partners are less likely than other alliances to be organized using formal equity-based contracts. He argues that close interaction between firms over prolonged periods leads to increased trust through mutual awareness and familiarity, making detailed equity-based contracts unnecessary. Kalnins and Mayer (2004) show that repeated contracting at a U.S. information technology services firm leads on average to less use of fixed-price contracts, although the effect of repeated contracting varies across client firms and sometimes leads to more use of fixed-price contracts.

In contrast, other articles find evidence that repeated interaction and formal fixed-price contracts might not necessarily be substitutes. Mayer (2000) studies the contracts of a specific U.S. information technology services firm and shows that high-powered formal contracts and repeated interaction are perceived to be complements. Banerjee and Duflo (2000) fail to find a significant effect of repeated contracting on the choice between cost-plus and fixed-price contracts in the Indian software industry.

Empirically we find that frequent repeated interaction reduces the use of high-powered contracts in the offshore oil-drilling industry, suggesting that repeated interaction and high-powered formal contracts are substitutes in this setting. To test the robustness of this finding, we use instrumental variables estimation to account for simultaneity issues and endogenous matching of agents to projects. None of the aforementioned studies address the simultaneity problem, though it has been shown to be potentially serious in other contexts—specifically, agricultural contract choice—by Ackerberg and Botticini (2002). We exploit the site-specific and asset-intensive nature of the offshore drilling industry to construct instruments for agent characteristics that we argue are exogenous to the choice of contract form. Comparing our instrumental variables results

3. In the rest of the article, for brevity, we will often refer to both ex ante contracting and ex post renegotiation costs as simply "contracting costs," though it should be clear from context that we are referring to both ex ante and ex post costs.

with our preliminary models shows that endogenous matching, if unaccounted for, would have led us to underestimate the magnitude of the effect of repeated interaction on contract choice.

In addition, we extend the empirical literature on fixed-price and cost-plus contracts to a new industry, using a dataset that offers several advantages over those used in previous studies. First, we analyze a much larger set of projects than the aforementioned studies. Second, while our projects (offshore oil and gas wells) differ in some important observable ways, they are arguably considerably more homogenous than the projects examined in previous studies [e.g., software development projects (Banerjee and Duflo, 2000), IT services outsourcing projects (Kalnins and Mayer, 2004), and alliances (Gulati, 1995)]. Third, we have a substantial number of agent firms, which provides us more variation in the level of repeated interaction among firms than was present in the two-contractor setting of Crocker and Reynolds (1993). Fourth, we have a panel with multiple projects for almost all principals, which allows us to control for principal heterogeneity in a way that Banerjee and Duflo (2000) and Kalnins and Mayer (2004) could not.

Section 2 describes the offshore drilling industry and the two major kinds of contracts employed there: day-rate (cost-plus) and turnkey (fixed-price) contracts. Section 3 states a number of empirical hypotheses drawn from the existing literature. Section 4 describes our data and the precise definitions of the variables used in the analysis. Section 5 presents our empirical models and describes our results. Section 6 concludes by situating our results in the context of the related empirical literature and by discussing directions for future research.

2. Offshore Drilling

Oil and gas exploration and production (E&P) companies lease offshore tracts from governments, typically through auctions. These E&P firms include the integrated majors (Shell and BP Amoco, for example, with tens of billions of dollars in assets), large independents (Anadarko and Vastar, for example, with assets in the $2–5 billion range), and many smaller firms (the smallest public firms in our data are Petroquest and Santa Fe Energy, each with assets less than $30 million). Having acquired the rights to a tract, these firms formulate a plan for its exploration. Typically this plan involves drilling several exploratory wells to determine the extent, composition, and economic viability of whatever fuels may be present within the tract. If the results are favorable, the exploratory wells are followed by development wells placed to efficiently extract these reserves.

Only a very small number of state-owned E&P companies own and operate their own offshore drilling rigs. All other firms, including all of the majors, contract for the services of drilling rigs with independent drilling contractors.[4] The independent drilling contractors include industry giants like Transocean Sedco Forex, Noble Drilling, and Global Marine (each with 30–120 rigs and $2–6 billion in assets) as well as much smaller firms that own only a handful of rigs or even a single rig. Rigs can be classified into two types: those that rest on the ocean floor (shallow-water rigs), and those that float while drilling (deepwater rigs). By far the most common type of shallow-water rig is the jack-up rig, which accounts for about two-thirds of the global rig fleet. The replacement value of a jack-up is $80–100 million. A standard jack-up houses a crew of 25–30 workers and can drill in 150–300 feet of water, depending on the model. Deepwater rigs that drill in up to 10,000 feet of water may cost as much as four times that much and house a slightly larger crew.

A drilling rig is used only for the drilling of the well, which requires 30–60 days in most cases. Once the well is drilled, the rig moves on to another job. Lighter-duty equipment and specialized services companies (e.g., Schlumberger and Halliburton) then move in for the installation of production equipment. Some of this production equipment then stays semipermanently fixed at the well location and is often owned by the E&P company, unlike the drilling rig.

Exploration and production companies contract with drilling contractors under two standard contract forms: day-rate and turnkey. Under a day-rate contract, the drilling contractor agrees to provide a staffed and functional rig for the duration of the project, in exchange for which it receives a daily payment called the day-rate. The contract typically specifies some minimal performance benchmarks that must be met to avoid penalties. Commonly, for example, the driller is penalized for downtime in excess of one day per month. Under such a contract, the drilling process is managed by two workers on the rig, one representing the E&P company and the other representing the driller. The E&P firm's "company man" makes a number of decisions, in consultation with the E&P firm's land-based engineering staff, about the speed of drilling, the type of bit used, the weight and viscosity of the "drilling mud" pumped down the well, and a number of other important technical dimensions of drilling. The drilling contractor's "tool pusher" manages the rig's crew and the maintenance of

4. Interestingly, the industry has been structured this way since its inception in the 1950s. Most drilling rigs are not specific to particular tracts, except inasmuch as they are difficult and costly to move. As a result, efficient use of these assets seems to be facilitated by the independent ownership of rigs. This allows rigs to be used on nearby tracts of different E&P companies to minimize relocation costs without forcing the E&P firms to do business directly with each other, which could be problematic from the standpoint of antitrust concerns or intellectual property protection. For highly specialized rigs that are more tract-specific (e.g., deepwater rigs and harsh environment rigs), E&P firms often make long-term contracts for the financing, construction, and operation of new rigs. This does not include the jack-ups deployed in the Gulf of Mexico, on which we focus. Similarly E&P companies own other types of assets (e.g., production platforms) that are more project-specific (by virtue of their being more permanently fixed in place structurally). Thus the fact that virtually no E&P companies own (jack-up) drilling rigs seems to result from their relative nonspecificity.

the rig. In the Gulf of Mexico, day-rate contracts govern the drilling of more than 80% of all wells.

The alternative contract form is a turnkey contract, under which an E&P company pays a fixed price for a well drilled to its specifications. The turnkey driller takes on the responsibility for (and must employ staff to manage) the technical and engineering aspects of drilling management described above, the logistics tasks of arranging for delivery of all necessary drilling supplies, and the hiring of subcontractors responsible for recording drilling progress ("loggers") and other specialized tasks. The drilling contractor then manages the entire drilling process (there is no "company man") and assumes all financial risk for cost overruns and delays in the completion of the well. Note that this contract does *not* shift the exploration risk: the E&P company still bears the risk of a "dry hole" and still gains all the upside should major reserves be discovered.

Typically the E&P company's staff formulates an exploration and development plan and decides which of the planned wells should be drilled under each type of contract. Next, they determine the drilling contractors likely to have rigs available in the area. They then solicit bids from a handful of drilling contractors and evaluate these bids based on rig capabilities, the rig's safety record, price, and other considerations. Finalizing a contract often requires further negotiation with the "winner" of this bidding process.

While there is a larger market in day-rate contracts than in turnkey contracts, every transaction is bid out and ultimately negotiated independently; there is no "market" in which firms act as price takers. E&P firms often receive bids inconsistent with their expectations, causing them to change contract types. For example, turnkey bids may come in very high relative to the firm's internal estimate of the cost of drilling the well itself with a rig hired under a day-rate contract. In such a case, the E&P company might reject all of the turnkey bids and solicit day-rate bids for the same project. Thus the final contract selection results from an iterative consideration of possible combinations of contract types and drillers.

Once drilling begins, progress is monitored by the E&P company under both types of contract. In a day-rate contract, the E&P firm's "company man" is physically present on the rig to observe activity on the rig and relay data (information from the "well logs") to the engineering staff at the E&P company's headquarters. In a turnkey contract, the E&P company monitors drilling progress through the well logs and occasional visits to the site. In either case, the E&P company observes the timeliness of well completion, the occurrence of worker and environmental accidents, the ease of working with the particular driller (especially if recontracting is required), and other considerations that factor into future contracting decisions.[5]

5. Note that the results of such monitoring can be construed as "learning," where the true type of the driller is revealed over time, or as "observing a noncontractible," where good and

3. Theoretical Considerations

This section draws on the existing theoretical literature in the economics of contracts to formulate a number of hypotheses about the determinants of the choice between the turnkey and day-rate forms. In general, this literature assumes efficient contracting—that is, the choice of the contract that yields the higher joint net surplus. This can be defined as the value generated by the project under contract type *i*, denoted V_i, less the total ex ante and ex post contracting costs C_i associated with that type of contract.[6] Thus a turnkey contract is chosen if

$$V_T - C_T > V_D - C_D,$$

where subscripts T and D denote turnkey and day-rate contracts, respectively. Rearranging the above, an E&P firm is then assumed to choose a turnkey contract when efficiency gains due to, for example, improved incentives more than compensate for increases in contracting costs, or

$$V_T - V_D > C_T - C_D.$$

3.1 Project Characteristics

One important observable well characteristic is the well type—whether it is an exploratory or development well. A significant determinant of the severity of contracting costs, C_T, is the likelihood of costly renegotiation. In this industry, this arises when information obtained during drilling substantially alters the desired path of the well. Exploratory and development wells differ dramatically in the opportunities to increase the value of the well by altering the specifications. Such opportunities arise most often as a consequence of recent advances in drilling technology that allow the underground structures and hydrocarbons to be monitored in real time ("measurement-while-drilling") and allow this information to be used to guide the well along nonlinear trajectories to maximize the extraction of oil and gas ("directional drilling"). These techniques are of much more importance on development wells, where efficient extraction of oil and gas is the primary objective. Thus contracting costs on turnkey contracts C_T are higher for development wells. As a result, *we expect turnkey contracts to be more attractive on exploratory wells.*

The second important observable well characteristic is water depth. Over time, the Gulf of Mexico has been explored from the shallower coastal waters out toward the deeper waters at the edge of the outer Continental Shelf (OCS) and ultimately beyond. As a result, geological

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bad outcomes today can be rewarded and punished in repeated-game fashion in the negotiation of subsequent contracts. However, since we do not observe the terms of each contract, but only its type, we cannot distinguish or study "good" and "bad" reputations, but only the effect of repeated interaction in general on contractual form.

6. Project value V_i is the realized value of the project, taking into account incentive problems; thus differences in incentives between contract types will be reflected in the differences in V_i.

conditions are much more well understood in shallower waters; moreover, much of this knowledge becomes public through the government-mandated publication of "well logs" within a certain number of years after drilling. Because of the relatively poorer information that is available, there is greater uncertainty in deeper-water wells, leading both to more complex contingencies that must be specified ex ante and to a greater likelihood of an opportunity to profitably renegotiate the initial contract. Both effects tend to increase C_T. In addition, the latter effect will be more important for development wells as argued above. As a result, *we expect turnkey contracts to be more attractive on wells drilled in shallower waters, and for this effect to be greater for development wells.*

3.2 Firm and Market Characteristics

The scale of the two contracting firms may be important in determining the optimal contract. Turnkey contracts shift risk onto the driller, which diminishes V_T if the driller is less risk-tolerant than the E&P company (e.g., if the driller is smaller and therefore less diversified in its exposure to these risks). In addition, turnkey contracts shift certain managerial tasks to the driller, requiring an engineering staff of some minimal scale to manage a small number of drilling projects.[7] The inability to achieve these scale economies again diminishes V_T if the driller is small relative to the E&P company. As a result, *we expect turnkey contracts to be more attractive when the E&P company is smaller and when the driller is larger.*[8]

Low day-rates in the market are likely to exacerbate incentive problems under day-rate contracts by lowering the value of the driller's outside option (i.e., a driller who finishes a job quickly either gets very low rates on a new day-rate project or idles the rig while looking for a new job). In this case, low day-rates imply a reduction in V_D, so that *turnkey contracts are more attractive when day-rates are low.*[9]

3.3 Repeated Interaction

While many articles suggest that repeated interaction can help to solve incomplete contracting problems, it is not clear whether repeated

7. According to industry sources, specialization of the geological and engineering expertise required to manage a drilling project implies a minimal staff of three to six professionals; keeping them fully employed requires 8–12 projects a year.

8. It is also possible that larger drilling contractors have more well-established reputations; to the extent that reputations substitute for strong formal contracts, this would lead larger drillers to do more day-rate contracts. Since we believe the scale effects to be quite strong, we expect turnkey contracts to be more attractive for larger drillers.

9. The same prediction results from the hypothesis that contractors cut turnkey margins in times of low day-rates and utilization, making turnkey contracts more attractive (the total turnkey price will reflect lower market day-rates, in addition to the possibly lower turnkey margin). Roughly, this reflects a relative reduction in the opportunity cost of time for the engineering staff at a turnkey driller, which cannot redeploy this staff to ongoing E&P projects as an E&P company can. This increases V_T.

interaction should primarily mitigate incentive problems (increasing V_D to make day-rate contracts more attractive) or contracting costs (reducing C_T to make turnkey contracts more attractive). As a matter of definition, *if more frequent interaction leads to less turnkey contracting, then repeated interaction and high-powered formal contracts are substitutes; if more frequent interaction leads to more turnkey contracting, then repeated contracting and high-powered formal contracts are complements*. A central objective of this article is to evaluate which of these better characterizes contracting behavior in the offshore drilling industry.

4. Data

Our data come from Offshore Data Services (ODS), a Houston-based firm that gathers and disseminates data on offshore drilling rigs. E&P companies buy these data to track rig availability and aid in soliciting bids on projects; contractors buy the data to track competitors' activities, including fleet additions and movements of rigs. The Offshore Rig Locator database contains monthly observations on every offshore rig in the competitive world marketplace. The data for the present analysis include monthly observations from January 1998 through October 2000.

The Offshore Rig Locator database provides data on the technical specifications of the rig, the rig's ownership, and the rig's contract status. It also gives characteristics of the well the rig is working on, including the water depth, the well type (exploratory or development), and the identity of the E&P company that controls the lease where the rig is working. From this, one can construct variables that capture E&P company and driller characteristics (e.g., total number of projects).

While the data are global in scope, turnkey drilling activities are not. In only two geographic regions (as defined by ODS) do turnkey contracts account for a nonnegligible fraction of observed rig-months. As a result, the present analysis focuses on only these two regions—the U.S. Gulf of Mexico and Mexican offshore waters (which, together, we refer to as simply the Gulf of Mexico).[10] We also restrict our analysis to projects using jack-up rigs, which account for more than three-fourths of projects in these regions over this time period. The homogeneity of the capabilities of jack-up rigs ensures that the projects we study are relatively comparable.

The unit of analysis of this study is the project (or well), as the fundamental question we ask is what determines whether a particular well is

10. Corts (2002) argues that there are two likely reasons that turnkey contracts are effectively limited to the Gulf of Mexico. First, the gulf is by far the largest offshore drilling market in the world. Adverse selection may impede turnkey contracting (since drillers worry that E&P companies will seek turnkey contracts only on wells they know to be especially difficult), and a large market may mitigate this problem by ensuring that drillers have ample opportunities to learn about local conditions through contracts with multiple drillers. Second, turnkey contracts are a relatively new contractual form in offshore drilling, surpassing 5% of gulf wells for the first time in 1991. Since all the major drilling contractors are headquartered in Houston, there may be a simple lag in diffusion of this new contracting technology.

drilled under a day-rate or turnkey contract. The data, in contrast, are organized by rig-month and include both observations on idle rigs and multiple observations for a single well that takes more than a month to drill. Therefore, to create observations at the project level, we examined changes in well characteristics and also the length of the project to ascertain when a new project began. First, we dropped all rig-months in which the rig's status was not "drilling." Second, all rigs that were drilling in the first month of the data were marked as new projects. We then assumed work on a new well began if at least one of the following conditions was satisfied: (1) the rig appeared in the data after not appearing in the previous month (i.e., its previous status was not "drilling"); (2) the E&P company on whose lease the rig was drilling changed from the previous month; (3) the water depth of the well the rig was drilling changed from the previous month; or (4) the well type changed from the previous month.

When a rig worked on an observationally identical well for more than two months, every other month was marked as the beginning of a new project since two months is the typical time required to drill a well. We then dropped all observations not deemed to mark the beginning of a new project. This left 1874 projects, 17% of which were drilled under turnkey contracts.

Table 1 provides some descriptive statistics on contracting in this industry. This table shows that virtually all E&P companies use a wide range of drillers and drill at least some wells under turnkey contracts. The next two subsections describe the variables used in the analysis, which are defined in Table 2. Summary statistics for these variables are given in Table 3.

4.1 Explanatory Variables

This subsection describes in more detail the variables used to proxy for the considerations of theoretical interest, as described in the hypotheses of Section 3. Project characteristics are straightforward. The dummy variable *exploratory* is set equal to one if the well is exploratory and zero if the well is a development well. Note that, consistent with the hypothesis given in Section 3, the split-sample means in Table 3 show that exploratory wells account for a larger proportion of turnkey wells than of day-rate wells. The other project characteristic is water depth, which measures the water depth, in hundreds of feet, at the well site.[11] Consistent with the hypothesis stated in Section 3, the split-sample means in Table 3 show that water depth is slightly higher for day-rate wells, though the difference is small.

We define *E&P company scale* as the number of rig-months of drilling on all of a particular E&P company's leases around the world over the 34 months covered in the present data. It measures the overall scale of the E&P company's drilling activities and is a time-independent constant for each

11. Water depth is reported by ODS in feet, and this level of precision is preserved in the analysis. We have rescaled the variable by dividing by 100 in order to scale the coefficients in the regressions so that they are easy to read in the tables.

Table 1. Summary of E&P Company-Driller Interactions for Jack-Up Projects in the U.S./Gulf of Mexico Region

	Driller											
E&P company	Global Marine	ENSCO	R&B Falcon	Noble Drilling	Rowan	Diamond Offshore	Marine Drilling	Pride Intl.	Parker Drilling	Cliffs Drilling	Other drillers	Total for E&P company
Chevron	33(17)	17(0)	11(0)	28(3)	6(0)	28(0)	2(0)	8(0)	18(0)			151(20)
Vastar Resources	20(5)	8(0)	2(1)	2(2)	6(0)	36(0)	15(0)			1(1)		90(9)
Spirit Energy 76	31(2)		19(0)	15(0)	2(0)			1(0)	8(0)	8(0)	5(0)	89(2)
PEMEX				30(5)							52(6)	82(11)
Coastal O&G	22(2)	20(0)			24(0)	12(0)						78(2)
Ocean Energy	16(4)		4(0)	4(2)			6(0)	3(0)	9(0)	10(0)		52(6)
Newfield Exploration	18(17)	7(0)	7(7)	5(5)	3(0)	2(1)	9(0)	1(0)				52(30)
Samedan	4(4)	6(0)	5(0)		25(0)		1(0)	9(0)	1(0)			51(4)
Apache Corp	1(1)	7(0)	9(0)	22(0)	6(0)	4(0)						49(1)
Basin Exploration	15(15)	2(0)	8(0)	5(3)		7(0)	7(0)		1(0)			45(18)
Exxon		42(0)										42(0)
Exxon Mobil	5(0)	37(0)										42(0)
Burlington Resources	1(1)	3(0)	4(1)	11(7)		1(0)	7(0)	10(0)	4(0)			41(9)
Sonat Exploration	13(11)	5(0)	20(0)	1(1)					1(0)			40(12)
Houston Exploration	1(1)	3(0)	6(1)	10(0)		2(0)	13(0)					35(2)
BP Amoco	5(4)	12(0)			8(0)	9(0)						34(4)
Walter O&G	3(1)	5(0)	1(1)		5(0)	2(0)	15(0)	2(0)				33(2)
Stone Energy	6(1)	3(0)	4(0)					17(0)		2(0)		32(1)
Bois d'Arc		1(0)	5(3)	2(2)		4(0)	1(0)	1(0)	16(0)			30(5)
Union Pacific Res	2(1)	4(0)	6(0)		11(0)	5(0)	2(0)					30(1)
Equitable Resources	14(13)	4(0)	8(1)							2(0)		28(14)
Hall Houston	3(3)	1(0)	9(3)		6(0)	2(0)	5(0)			1(0)		27(6)

Spinnaker	5(5)	4(0)	7(0)	5(5)			4(0)	2(0)				27(10)
Anadarko	5(1)				21(0)							26(1)
Shell	1(0)	2(0)	1(0)		3(0)	1(0)		15(0)			2(1)	25(1)
Other E&P companies	136(98)	132(0)	106(27)	58(22)	66(0)	21(1)	48(0)	20(0)	21(0)	25(5)	10(0)	643(153)
Total for driller	360(207)	325(0)	242(45)	198(57)	192(0)	136(2)	135(0)	89(0)	79(0)	49(6)	69(7)	1874(324)

Each entry in this table represents the number of projects undertaken by the driller in that column for the exploration and production (E&P) company in that row. The figure in parentheses gives the number of these projects carried out under a turnkey contract. For clarity of presentation in this table, firm-level data on only the largest drillers and E&P companies is shown here. The eight smallest drillers have been aggregated under ''Other drillers,'' and the 102 smallest E&P companies have been aggregated under ''Other E&P companies.'' All regression models presented later, however, do use firm-level data for all 18 drillers and all 127 E&P companies in our data.

Table 2. Description of Variables

Variable	Description
Turnkey	Binary variable equal to one if well is drilled under a turnkey contract; zero if day-rate contract
Exploratory	Binary variable equal to one if well the is exploratory; zero if development
Water depth	Water depth at well site, measured to nearest foot, reported in hundreds of feet
Day-rate	Average day-rate, in thousands of dollars, paid to drillers in the Gulf of Mexico in particular month
E&P company scale	Total number of projects worldwide for particular E&P company from January 1998 through October 2000
Driller scale	Total number of projects worldwide for particular driller from January 1998 through October 2000
Recent contracts	Number of projects worldwide involving particular operator-driller pair in the preceding six months

Table 3. Summary Statistics for Jack-Up Wells in the U.S./Gulf of Mexico Region

Variable	Observations	Mean	Std. Dev.
Overall			
Turnkey	1874	0.17	0.38
Exploratory	1874	0.45	0.50
Water depth	1874	1.19	0.84
Dayrate	1874	24.53	9.81
E&P company scale	1874	112.90	113.84
Driller scale	1874	657.29	312.54
Recent contracts	1476	5.19	5.55
Day-rate contract			
Exploratory	1550	0.40	0.49
Water depth	1550	1.20	0.84
Dayrate	1550	24.68	9.86
E&P company scale	1550	120.30	115.93
Driller scale	1550	605.93	311.26
Recent contracts	1210	5.67	5.75
Turnkey contract			
Exploratory	324	0.66	0.48
Water depth	324	1.15	0.87
Dayrate	324	23.77	9.58
E&P company scale	324	77.48	95.77
Driller scale	324	903.01	169.17
Recent contracts	266	3.00	3.80

E&P company. We define *driller scale* similarly. The split-sample means in Table 3 show that turnkey contracts tend to involve smaller E&P companies and larger drillers, consistent with the hypotheses from Section 3.

Day-rate is the average day-rate in the U.S. Gulf of Mexico region for the current month.[12] Consistent with the hypothesis in Section 3, the split-sample means show that turnkey contracts tend to be used in lower-day-rate periods, though the difference in values for the two contract types is quite small.

We constructed a variable called *recent contracts* to measure the frequency of interaction between a particular E&P company and a particular driller in the recent past. Specifically we define *recent contracts* as the number of projects the particular E&P company-contractor pair have worked on together in the previous six months.[13] Naturally this variable is undefined during the first six months of data, so all analysis involving *recent contracts* is based on projects between July 1998 (month 7) and October 2000 (month 34).[14] The split-sample means in Table 3 show that the mean value of *recent contracts* for day-rate wells (5.7) is much higher than that for turnkey wells (3.0), which is suggestive of the finding that repeated interaction and high-powered formal contracts are substitutes.

4.2 Instruments

The U.S. Gulf of Mexico is divided into a number of subregions for purposes of tract leasing and management. The subregions of the OCS are irregularly sized and shaped, following the natural contours of the shoreline and the OCS, while deepwater tracts are rectangular. The jack-up rigs on which we focus work only on OCS tracts. While there are a few small subregions very near the coast, most of the 25 OCS regions are "slices" of the gulf running from the coast to the edge of the OCS. Thus most regions encompass a wide range of water depths. Roughly the subregion of the gulf that a well is in indicates where it lies along the coast, while the water depth indicates its distance from shore.

While we do not observe the exact location of the rig, we do know its subregion within the gulf. We use this to construct measures of the

12. This is a measure of the average day-rate reported by ODS. We do not know the day-rates (or turnkey prices) associated with any of the particular contracts we observe. We also used an alternate measure of market conditions—the monthly rig utilization rate in the Gulf of Mexico. This measure is highly correlated with *day-rate* and gives almost identical results in the regressions. We therefore report only results using *day-rate*.

13. Ideally one would like to differentiate "good experiences" and "bad experiences" between two parties, since they might well have different effects on subsequent choice of contract form. However, we observe no outcome measures and so can calculate only the total number of recent projects.

14. As a robustness check, we also ran a subset of our regressions using a definition for *recent contracts* based on time windows shorter as well as longer than 6 months. All our qualitative results remained unchanged. Also, a forward-looking game theoretic model might suggest looking at interactions in the near future rather than the recent past. However, we found that such a definition had much less explanatory power. One explanation could be that the actual future realizations were a poor proxy of the *expected* future interactions at the time of contract, and that past interactions provide a better proxy of the expectations regarding the future.

characteristics of drillers that have rigs in the region local to a particular project. Since moving rigs long distances is expensive and time-consuming, this provides a way of identifying likely winners on particular projects and determining their characteristics.[15] Specifically, we define two new variables as the expected value of *recent contracts* and *driller scale*, respectively, that would obtain if the E&P company in question was randomly matched with one of the rigs that was already in the subregion in the previous month. We then use these as instruments for the characteristics of the *winning* contractor in our IV specifications.

5. Empirical Analysis

The above discussion suggests a natural way to proceed with the empirical analysis: apply a standard discrete choice model like logit or probit to the contract choice problem, controlling for the characteristics of the E&P company and the driller, controlling for observed project characteristics like water depth and well type, and including some measure of the frequency of interaction. Section 5.1 presents results from this straightforward approach as a baseline.

This simple approach assumes that the contractor is known with certainty before the contract type is determined, as it treats driller-specific characteristics like *driller scale* and *recent contracts* as exogenous explanatory variables. In fact, however, the timing in this industry seems to be inconsistent with this, as bids for a particular contract type are solicited from numerous contractors *before* a driller is chosen. Since the type of contract affects which contractor wins the bidding and the E&P companies' information regarding the identity of the likely winning contractor (which is unobservable to us as econometricians) affects the choice of contract type, the driller and contract type should be treated as simultaneously determined. It is also plausible that project characteristics unobserved by the econometrician but observed by the E&P companies give rise to the "endogenous matching" problem documented by Ackerberg and Botticini (2002) in similar models. Section 5.2 addresses these issues through instrumental variables estimation.

5.1 Contractor Determined Before Contract Type

The most straightforward way to estimate the effect of repeated interaction on contract choice is to assume that the particular E&P company and driller who ultimately sign a contract already know they will work together prior to the determination of the type of contract. Though it seems inconsistent with the actual timing in the industry (where E&P companies typically ask for formal bids after having decided whether they want to execute the project as day-rate or turnkey), this specification provides a

15. In fact, 56% of the rigs in our data stay in the same subregion from one project to the next.

useful baseline and is directly comparable to the approach employed in virtually all the existing literature.

5.1.1 Empirical Model. Let t represent the contract type, where $t = 0$ represents a day-rate contract and $t = 1$ represents a turnkey contract; let X represent the vector of project characteristics; let P be the vector of principal (E&P company) characteristics; and let D be the vector of driller characteristics other than the frequency of interaction r. (In fact, through most of the article, D simply measures the driller's scale.) Denote the net gain from using a turnkey contract over a day-rate contract, which is $[(V_T - C_T) - (V_D - C_D)]$ in the notation of Section 3, as $G(X, P, D, r) + \epsilon$, where ϵ is a symmetric mean zero error capturing unobserved factors affecting the relative merit of the two types of contracts. The E&P company chooses the turnkey contract if $G(X, P, D, r) + \epsilon > 0$ or, equivalently, $\epsilon < G(X, P, D, r)$. We impose a simple linear form for the net gain function G, that is, $G(X, P, D, r) = \alpha_0 + \alpha_1 X + \alpha_2 P + \alpha_3 D + \alpha_4 r$, and assume that ϵ has a cumulative logistic distribution F.[16] This yields the standard logit model

$$\Pr(t = 1) = F(\alpha_0 + \alpha_1 X + \alpha_2 P + \alpha_3 D + \alpha_4 r).$$

Because of the panel nature of our data, the error ϵ may not be independently distributed or homoscedastic. In particular, choices made on projects undertaken by the same E&P company are likely to be correlated. Therefore, in the simple pooled regression, we report Huber-White robust standard errors, allowing for clustering among the observations of each E&P firm to give conservative standard errors in case the errors are not independent.

We next exploit the panel structure of our data to estimate alternate models that account for the heterogeneity of the E&P companies in a number of alternative specifications. These models follow from different assumptions on the components of the error term for project j undertaken by E&P company i. We assume an error structure of the form $\epsilon_{ij} = \mu_i + \eta_{ij}$, where μ_i is the "E&P company effect" for firm i and η_{ij} is the error specific to project j. We begin by assuming that the μ_i's are independently and identically distributed draws from a common normal distribution and the η_{ij}'s are independently and identically distributed with a logistic cumulative distribution. Under these circumstances, the random effects logit model is efficient. However, since the random effects model can lead to inconsistent estimates if the above assumption does not hold, we also estimate a fixed-effects logit model, where the μ_i's are treated as constants

16. In writing the econometric models, we omit interaction terms for simplicity of exposition, but we do include interaction terms in the actual empirical analysis. In addition to the linear form for G, we tried more complex functional forms. This did not add much to the predictive power and did not change the qualitative results, so we have not reported those results in the article.

instead of being assumed to be independently drawn from a given distribution.[17] A Hausman test fails to reject the equality of the results from the two models, indicating that the random effects assumptions cannot be rejected. Since the model with random effects for E&P companies is a more efficient estimator than the fixed-effects estimator (when the random effects assumptions hold), we adopt the random effects model as our preferred specification.

We also test the robustness of our results to driller-specific effects. The random effects model is not an appropriate model to use for drillers since bifurcation of drillers into those who offer turnkey contracts and those who do not makes implausible the random effects model's assumption that the errors are independently drawn from a common distribution. Therefore we use dummy variables to capture driller effects.[18]

The results of empirical analysis based on the above specification are reported in Tables 4 and 5. For ease of exposition, Table 4 reports the results from all the models mentioned above without any interactions among variables. Table 5 allows for interactions among variables, while using our model of choice, that is, E&P company random effects combined with driller fixed effects.

5.1.2 Empirical Results: Alternative Controls for Firm Heterogeneity.

In Table 4, column (i) is the simplest possible logit model, regressing *turnkey* on *recent contracts* alone. Since we define the *recent contracts* variable as the number of times the two parties to a contract have interacted in the previous six months, we must omit the first six months of data from this analysis. Therefore only 1476 of the total of 1874 observations are used. The coefficient on *recent contracts* is negative and significant, indicating that more frequent interaction seems to reduce reliance on turnkey contracts. The standard errors have been corrected for heteroscedasticity as

17. Since the number of observations per E&P company is small, the individual fixed-effects μ_i's cannot be consistently estimated, and the nonlinearity of the logit model would therefore also lead to inconsistent estimates of the coefficients of interest if a simple maximum-likelihood approach is used. However, this can be remedied by using a conditional fixed effects approach. To see how, define $\mathbf{t}_i \equiv (t_{i1}, \ldots, t_{iT_i})'$ as the vector of binary outcomes for all T_i projects of driller i and define $n_i \equiv \sum_{j=1}^{T_i} t_{ij}$. It can be shown that the joint distribution of $\mathbf{t}_i$ conditional on n_i and all the explanatory variables (including the driller effect μ_i) is independent of μ_i. Thus conditional maximum-likelihood methods can be used to consistently estimate the coefficients of interest despite the fact that there are not enough observations per E&P company to consistently estimate the μ_i's [see Chamberlain (1984), Wooldridge (2002: 490–492), Greene (2003:697–699)].

18. Note that only 69 of the 1874 projects in Table 1 appear under "other drillers," and are not covered by the 10 drillers we list individually. In contrast, 643 of the 1874 projects appear under "other E&P companies," and are not covered by the 25 E&P companies we list individually. Since a small number of drillers dominate the offshore drilling industry, the number of observations per driller is large and increases with the number of observations. Thus fixed effects for individual drillers can be consistently estimated by including dummy variables. For the much more numerous E&P companies, we instead estimate conditional fixed effects.

Table 4. Effect of Repeated Interaction Under Alternate Regression Models

Dependent variable: *Turnkey*	i) Logit with robust standard errors and clustering on E&P	ii) Logit with robust standard errors and clustering on E&P	iii) Logit with random effects for E&P company	iv) Logit with random effects for E&P company and fixed effects for driller	v) Logit with conditional fixed effects for E&P company	vi) Logit with conditional fixed effects for E&P company and fixed effects for driller
Recent contracts	−0.1298***	−0.1382***	−0.1101***	−0.1471***	−0.0863***	−0.1097**
	(0.0439)	(0.0498)	(0.0286)	(0.0415)	(0.0285)	(0.0429)
Exploratory		0.9895***	0.9809***	1.3421***	0.7604***	1.0625***
		(0.2021)	(0.2109)	(0.2813)	(0.2198)	(0.3003)
Water depth		−0.2019	−0.1185	−0.1930	−0.0421	−0.0583
		(0.1464)	(0.1219)	(0.1657)	(0.1325)	(0.1817)
Day-rate		0.0131	−0.0001	0.0056	−0.0144	−0.0102
		(0.0133)	(0.0148)	(0.0189)	(0.0156)	(0.0205)
E&P company scale		−0.0011	−0.0022*	−0.0034**		
		(0.0012)	(0.0013)	(0.0016)		
Driller scale		0.0097**	0.0100***		0.0086***	
		(0.0045)	(0.0011)		(0.0011)	
d(E[*Turnkey*])/d(*Recent contracts*)	−0.0175***	−0.0179***	−0.0142***	−0.0227***		
	(0.0051)	(0.0038)	(0.0036)	(0.0065)		
d(E[*Turnkey*])/d(*Exploratory*)		0.1339***	0.1321***	0.2134***		
		(0.0360)	(0.0346)	(0.0515)		
d(E[*Turnkey*])/d(*Water depth*)		−0.0261	−0.0152	−0.0298		
		(0.0171)	(0.0159)	(0.0259)		
N	1476	1476	1476	791	1159	665

Standard errors are given in parentheses.
Marginal effects calculated at means of all variables except *Driller scale*, which is held at its median.
***$p < .01$, **$p < .05$, *$p < .10$.

Table 5. Interactions Among Explanatory Variables

Dependent variable: *Turnkey*	i) Logit with random effects for E&P company	ii) Logit with random effects for E&P company	iii) Logit with random effects for E&P company and fixed effects for driller	iv) Logit with random effects for E&P company and fixed effects for driller
Recent contracts	−0.1131***	−0.1231***	−0.1596***	−0.1645***
	(0.0286)	(0.0294)	(0.0423)	(0.0435)
Exploratory	1.0146***	0.8384***	1.4370***	1.3322***
	(0.2129)	(0.2338)	(0.2863)	(0.3159)
Water depth	−0.2521*	−0.2399*	−0.3409*	−0.3874**
	(0.1341)	(0.1455)	(0.1779)	(0.1912)
*Exploratory * Water depth*	0.8642***	0.8481***	1.3244***	1.2592***
	(0.2518)	(0.2587)	(0.3398)	(0.3444)
*Recent contracts * Exploratory*		−0.1055**		−0.0767
		(0.0515)		(0.0729)
*Recent contracts * Water depth*		0.0011		−0.0407
		(0.0332)		(0.0456)
Day-rate	0.0010	0.0024	0.0096	0.0083
	(0.0150)	(0.0148)	(0.0194)	(0.0195)
E&P company scale	−0.0022*	−0.0023*	−0.0037**	−0.0041**
	(0.0013)	(0.0013)	(0.0017)	(0.0017)
Driller scale	0.0101***	0.0102***		
	(0.0011)	(0.0011)		
d(E[*Turnkey*])/d(*Exploratory*)	0.1323***	0.1010***	0.2389***	0.2150***
	(0.0337)	(0.0337)	(0.0559)	(0.0615)

Exploratory wells:				
d(E[*Turnkey*])/d(*Recent contracts*)	−0.0200***	−0.0287***	−0.0363***	−0.0455***
	(0.0049)	(0.0063)	(0.0094)	(0.0127)
d(E[*Turnkey*])/d(*water depth*)	0.0405	0.0366	0.0900*	0.0688
	(0.0281)	(0.0291)	(0.0523)	(0.0565)
Development wells:				
d(E[*Turnkey*])/d(*Recent contracts*)	−0.0100***	−0.0066**	−0.0165***	−0.0134***
	(0.0027)	(0.0029)	(0.0050)	(0.0054)
d(E[*Turnkey*])/d(*water depth*)	−0.0560***	−0.0534***	−0.0958***	−0.0973***
	(0.0189)	(0.0183)	(0.0316)	(0.0318)
N	1476	1476	791	791

Standard errors are given in parentheses.
Means have been subtracted before interacting, so uninteracted coefficients can be interpreted as overall coefficient at means.
Marginal effects calculated at means of all variables except *Driller scale*, which is held at its median.
***$p < .01$, **$p < .05$, *$p < .10$.

well as possible correlation within each E&P company. We calculate the marginal effect at the mean value of *recent contracts* and find that an increase of *recent contracts* by one leads to a decrease in probability of choosing a turnkey contract by about 1.8%.[19]

Column (ii) repeats the regression from column (i), but now includes variables to control for the well type (exploratory versus development), the water depth of the well, the average day-rate for the current month, and the scale of the E&P company and the driller. Column (iii) includes the same set of independent variables in a specification with random effects for each E&P firm. Since, as discussed above, our preferred model includes random effects for E&P firms, we discuss the results from column (iii) in some detail.

The coefficient on *recent contracts* is negative and significant, with a marginal effect of around 1.4%. In addition, we find that the coefficient on *exploratory* is positive and significant, indicating that exploratory wells are more likely to be drilled under turnkey contracts. The marginal effect of going from a development well to an exploratory well, other things being equal, is a 13.2% increase in the probability of a turnkey contract. This positive effect reinforces the simple observation from the summary statistics that turnkey contracts are more prevalent in exploratory wells than in development wells. It is also consistent with the hypothesis in Section 3.1 that suggests that the contracting costs inherent in turnkey contracting are especially severe for development wells.

The coefficient on *water depth* is negative, though not statistically significant. The marginal effect on probability of a turnkey contract is a 1.5% decrease in probability with a 100 foot increase in well depth, though this is statistically insignificant. We will later see that *water depth* does become significant when we consider its effect on development wells separately. An increase in the *day-rate* is found to have essentially no impact on the probability of using a turnkey contract.

An increase in *E&P company scale* is found to decrease the use of turnkey contracts, though the effect is statistically significant only at the 10% level. On the other hand, *driller scale* is found to have a positive and significant effect. This suggests that large E&P companies may be less likely to employ turnkey contracts, while large drillers are significantly more likely to take on turnkey projects. This is consistent with the hypotheses in Section 3.2 that emphasize that turnkey contracts shift both risk and certain technologically sophisticated decision-making responsibility to the driller. Both of these burdens are likely to be more cheaply borne by

19. This is calculated at the mean values of all variables except *driller scale*, which is held at its median. *Driller scale* is held at its median because of its highly skewed distribution and its overwhelmingly strong influence on contract choice when it is small in value (small drillers simply do not do turnkey projects). The marginal effect remains statistically significant, though slightly smaller in magnitude, when *driller scale* is held at its mean too.

larger firms, as larger firms are likely to be more risk tolerant and are better able to achieve the scale required to keep the requisite staff of engineers fully employed in project management tasks.

Column (iv) repeats column (iii), but with driller fixed effects included as well. Column (iv) uses only 791 observations, as it drops the drillers for whom there is no variance in the dependent variable. The qualitative results remain unchanged, but the effect of repeated interaction is now larger since observations for the drillers that had no variation in project type (and hence were "muting" the average effect) are not relevant in the fixed-effects model.

As an additional check of robustness, columns (v) and (vi) repeat the analysis from columns (iv) and (v) by using a fixed-effects model instead of a random effects model for E&P company effects.[20] The qualitative results from columns (iv) and (v) remain essentially unchanged. In fact, a Hausman test fails to reject equivalence of coefficients from columns (iii) and (v), and of those from columns (iv) and (vi). Therefore the random effects specification is not rejected and we adopt it as our specification of choice for E&P company effects.

To summarize, the specifications in Table 4 produce similar results. In particular, both the *recent contracts* and *exploratory* variables have negative and significant coefficients in every specification; these coefficients are fairly stable across specifications. In addition, the *E&P* and *driller scale* measures are significant and have the expected signs in all the specifications that include any sort of control for firm heterogeneity.[21]

5.1.3 Empirical Results: Regressions with Interactions. Table 5 explores the effect of interactions among *recent contracts*, *water depth*, and *exploratory* on contract choice. Column (i) of Table 5 repeats the analysis from our preferred specification (Table 4, column (iii)), but now with an interaction term for *exploratory* and *water depth* included as well. Column (ii) is a variant of column (i) that also considers the differential effect of repeated interaction on turnkey usage on exploratory versus development

20. Note that we do not report marginal effects in column (v) and (vi) since the E&P company effects, which would be needed to compute the marginal effects because of the nonlinearity of the logit model, are not consistently estimated in the fixed-effects approach.

21. The differences between exploratory and development projects could mean that past interactions on different kinds of projects have different effects on contract choice for subsequent projects. In order to check for this possibility, we repeated the analysis by constructing two variables that measured the past six month's projects between a pair of firms on each well type, and substituting these two variables for the single measure of *recent contracts* used in the results reported in the article. We found that both measures of repeated interaction had negative and significant signs. While the effect was somewhat larger at the point estimate for *recent contracts* on development wells, the coefficients were not significantly different. Similar results held when we repeated the same analysis on exploratory-only and development-only subsamples.

wells and on deep versus shallow wells. This specification adds an interaction term for *recent contracts* and *exploratory* and one for *recent contracts* and *water depth*.

The new finding in this table is that interaction between *water depth* and *exploratory* is significant.[22] While *water depth* has a negative effect (significant at 10%) on the fraction of turnkey projects on average, this effect is larger (more negative) for development wells than for exploratory wells. We find that the marginal effect of water depth on the use of turnkey is negative and significant for development wells in every specification in Table 5, consistent with the hypothesis in Section 3.1 that the increasing complexity of deeper-water wells exacerbates the contracting costs associated with turnkey contracts. The effect is significant in magnitude as well; on a development well, a 100 foot increase in water depth increases the probability of choosing a turnkey contract by more than 5% in every specification. In contrast, the net marginal effect of *water depth* is insignificantly different from zero for exploratory wells. This is consistent with the hypothesis that such contracting costs are more severe on development wells.

The interaction between *recent contracts* and *water depth* in column (ii) is insignificant. However, the interaction between *recent contracts* and *exploratory* shows that, while repeated interaction has a negative effect on turnkey contracts for both well types, the effect is much stronger for exploratory wells (where turnkey contracts are more prevalent). This indicates that it is most attractive to substitute repeated interaction for high-powered turnkey contracts on precisely those wells where turnkey contracts are otherwise most used—that is, on those projects where incentive problems are most severe. This is consistent with the idea that repeated interaction is primarily mitigating incentive problems, not contracting costs.

Analogous to column (iv) in Table 4, we also check the robustness of this section's results to driller-specific effects by repeating the analysis of columns (i) and (ii) of Table 5 by now including fixed effects for the driller. The outcome is reported in columns (iii) and (iv). All the results discussed above remain robust to controlling for driller effects.

5.2 Contract Type and Driller Determined Simultaneously

Strictly speaking, the model in Section 5.1 is correct only under the assumption that the contract type and driller choice decisions are made sequentially by the E&P company. In particular, since driller characteristics (*driller scale* and *recent contracts*) are treated as exogenous explanatory variables, that model assumes that the driller is chosen prior to the type of contract.

22. In all interaction terms, means have been subtracted from the respective variables before interacting them. Thus the net coefficients can be read directly from the table even in the presence of interaction terms. To help interpret the magnitude, we have also reported the marginal effects near the bottom of the table.

This section allows the possibility that the contract type and driller are determined simultaneously. Even if these decisions are not literally made at the same time, this is a more appropriate model if the decisions are made through an iterative process involving informal discussions, renegotiation, and rebidding or if the E&P company has information (that we as econometricians do not observe) that influences its expectations of how the second decision will be affected by its choice in the first decision. In either case, the models of Section 5.1 would be plagued by a correlation of the error with the variables of interest, inducing a bias in our estimates. In this section we use instrumental variables to estimate a simultaneous choice model that addresses these concerns. In addition, the instrumental variables approach also corrects for bias that may be induced by "endogenous matching" of agents to projects, which in general induces a problematic correlation between the contract choice error and driller characteristics if the matching between the E&P companies and the drillers is not random, but a function of unobserved project characteristics.

5.2.1 Empirical Model and Instrumenting Strategy. Consider a version of our empirical model in which the E&P company endogenously determines the contract type and the driller, and where the only relevant characteristic of the driller is the frequency of its interaction with the E&P firm.[23] In reduced form, the choice of driller can therefore be equivalently seen as directly choosing r. For ease of exposition, we simplify by assuming that the variables are continuous rather than discrete and that their respective structural equations are linear. This simplified model yields a two-equation simultaneous system:

$$t = \beta_0 + \beta_1 X + \beta_2 P + \beta_3 r + \epsilon$$
$$r = \gamma_0 + \gamma_1 X + \gamma_2 Z + \gamma_3 t + \eta.$$

Here, Z represents a vector of the characteristics of potential winning drillers; this affects the principal's choice of driller on a particular project, but does not directly figure into the contract choice. This might include, for example, the number of rigs that particular drillers have available nearby with appropriate technical specifications. The errors ϵ and η are assumed to be uncorrelated with X, P, and Z. Note that if turnkey contracts and repeated interaction are substitutes, then β_3 and γ_3 are both negative; if complements, both are positive.

First consider the case in which ϵ and η are not correlated with each other; for reasons that will become clear, we refer to this as the case of no endogenous matching. The only problem with directly estimating the first equation is that, because of the endogeneity induced by the second equation, ϵ is not uncorrelated with r. In particular, r contains $\gamma_3 t$, which is

23. In fact, in the model we estimate, *driller scale* is a second endogenous driller characteristic. We describe below how we handle this; for ease of exposition, we focus first on the model with only one endogenous driller characteristic.

negatively correlated with ϵ when turnkey contracts and repeated interaction are substitutes. This imparts a negative bias to β_3, that is, makes it larger in absolute value.[24]

Now consider the further complication that arises if ϵ and η are correlated as well. Ackerberg and Botticini (2002) term this "endogenous matching," emphasizing that unobserved project characteristics are likely to induce matching of agents to projects in a way that induces bias in the coefficients. For example, suppose there is a well that the principal expects to have especially severe incentive problems for reasons unobservable to the econometrician. In this case the principal is likely to choose a high-r driller and to do the job under a turnkey contract; that is, ϵ and η are positively correlated. Now direct estimation of the contract choice equation suffers from an additional source of correlation of r and ϵ. Specifically, r contains both $\gamma_3 t$, which is negatively correlated with ϵ when turnkey contracts and repeated interaction are substitutes, and η, which is positively correlated with ϵ. Thus it is impossible to unambiguously sign the bias when turnkey contracts and repeated interaction are substitutes, since simultaneity as described above imparts a negative bias, but endogenous matching imparts a positive bias.[25]

In order to address these problems of simultaneity and endogenous matching, we use instrumental variables techniques to eliminate the correlation between r and ϵ. Note that in fact the problem is more complex than the two-equation model above, since driller scale is also endogenous. We therefore need instruments for both types of agent characteristics: variables that have explanatory power in determining the winning driller (and hence *recent contracts* and *driller scale*), but do not otherwise affect contract choice (except through this indirect effect on driller choice).

The instrument for *recent contracts*, which we will call *average local contracts*, is defined as the hypothetical expected value of the *recent contracts* variable if the drilling project were to be assigned randomly to one of the rigs already present in the geographic subregion in the previous month. Specifically, it is calculated as the weighted average of the *recent contracts* variable for the current E&P company and each potential winning contractor, weighted by each driller's fraction of the total number of rigs present in that subregion of the gulf in the previous period.[26] As an example, imagine a project in some subregion where there were three rigs in the previous period, two of them owned by driller A and one of

24. In contrast, if turnkey contracts and repeated interaction are complements, r is positively correlated with ϵ, which imparts a positive bias to β_3. We emphasize the result for the substitutes case, since this is the case indicated by our data.

25. In contrast, when turnkey contracts and repeated interaction are complements, both sources of correlation between r and ϵ induce positive bias. In either case, the effect of endogenous matching itself is to create a positive bias in the measure of the effect of repeated interaction on turnkey choice.

26. When no drillers had rigs in the relevant subregion in the previous period, all drillers in the data were assigned an equal weight instead.

them owned by driller *B*. Also assume that the number of projects between the given E&P company and driller *A* in the past six months is 15 and the number of projects between the E&P company and driller *B* in the past six months is 9. Then the value of *average local contracts* for the given observation is $(2/3)*15+(1/3)*9=13$. Similarly, the instrument for *driller scale*, which we will call *expected driller scale*, is defined as the ex ante expected value of the *driller scale* variable if the drilling project were to be randomly assigned to one of the rigs that were already present in the neighborhood in the past period. So, in the above example, if the driller scale were 300 for driller *A* and 150 for driller *B*, the value of *expected driller scale* will be $(2/3)*300+(1/3)*150=250$.

The validity of these instruments depends on two arguments. First, because rigs are costly to move, the winning driller (and hence the resulting value of *recent contracts* and *driller scale* variables) should be partly determined by which contractors already have their rigs in the same local region. This can be directly tested by performing an *F*-test of the exclusion of the instruments from the "first-stage" projection of the endogenous variables on the instruments and exogenous variables. The hypothesis that the instruments' coefficients are jointly zero is rejected at 1%, indicating that the instruments do have predictive power. Second, the instruments must be properly excluded from the contract choice equation. In other words, the characteristics of a driller should affect contract choice only through the possibility that this driller is in fact selected. This seems plausible (though we discuss caveats below); however, it cannot be tested explicitly in the absence of overidentification.

While we would ideally estimate a discrete-choice model with instrumental variables, a search of the econometric literature on the use of instrumental variables in discrete choice models [e.g., Maddala (1983), Newey (1987), and Wooldridge (2002)] did not produce a well-documented approach to doing so in a random effects framework. We therefore estimate an instrumental variables linear probability model, which does allow us to incorporate random effects for E&P companies, as in our earlier (non-IV) specifications.[27]

5.2.2 Empirical Results. Table 6 reports the results from regressions using the instrumental variables described above. Columns (i) and (iii) report two basic linear probability models with random effects for E&P companies and without instrumental variables, first with *recent contracts* included and then with this measure also interacted with *exploratory* and *water depth*. These regressions parallel columns (i) and (ii), respectively, from Table 5 for the logit case. They establish the baseline results for the linear model to provide a point of comparison for the IV results, since the

27. Newey (1987) provides an IV-based estimator for discrete choice models, though he does not model random effects. As a robustness check, in results not reported here, we also tried to use his estimator and found that our main results persist.

Table 6. Controlling for Simultaneity and Endogenous Matching Using Instrumental Variables

Dependent variable: *Turnkey*	i) Linear regression with random effects on E&P company	ii) Linear regression with random effects on E&P company, with IVs	iii) Linear regression with random effects on E&P company	iv) Linear regression with random effects on E&P company, with IVs
Recent contracts	−0.0081***	−0.0101**	−0.0093***	−0.0150***
	(0.0020)	(0.0047)	(0.0020)	(0.0051)
Exploratory	0.0988***	0.0909***	0.0943***	0.0797***
	(0.0188)	(0.0207)	(0.0188)	(0.0215)
Water depth	−0.0149	−0.0080	−0.0146	−0.0069
	(0.0110)	(0.0130)	(0.0110)	(0.0134)
*Exploratory * Water depth*	0.0688***	0.0751***	0.0668***	0.0750***
	(0.0204)	(0.0213)	(0.0207)	(0.0226)
*Recent contracts * Exploratory*			−0.0101***	−0.0211***
			(0.0034)	(0.0070)
*Recent contracts * Water depth*			0.0000	0.0014
			(0.0020)	(0.0036)
Day-rate	−0.0005	−0.0005	−0.0011	0.0000
	(0.0011)	(0.0016)	(0.0011)	(0.0016)
E&P company scale	−0.0004	−0.0003	−0.0004	−0.0002
	(0.0002)	(0.0002)	(0.0002)	(0.0002)
Driller scale	0.0005***	0.0003	0.0005***	0.0003
	(0.0000)	(0.0002)	(0.0000)	(0.0002)
d(E[*Turnkey*])/d(*Exploratory*)	0.0988***	0.0909***	0.0943***	0.0797***
	(0.0188)	(0.0207)	(0.0188)	(0.0215)

Exploratory wells:				
d(E[*Turnkey*])/d(*Recent contracts*)	−0.0081***	−0.0101**	−0.0150***	−0.0267***
	(0.0020)	(0.0047)	(0.0030)	(0.0076)
d(E[*Turnkey*])/d(*Water depth*)	0.0233	0.0339*	0.0226	0.0348*
	(0.0153)	(0.0181)	(0.0156)	(0.0194)
Development wells:				
d(E[*Turnkey*])/d(*Recent contracts*)	−0.0081***	−0.0101**	−0.0048**	−0.0057
	(0.0020)	(0.0047)	(0.0023)	(0.0048)
d(E[*Turnkey*])/d(*Water depth*)	−0.0455***	−0.0414***	−0.0442***	−0.0402***
	(0.0147)	(0.0156)	(0.0147)	(0.0157)
N	1476	1476	1476	1476

Standard errors are given in parentheses.
Means have been subtracted before interacting, so uninteracted coefficients can be interpreted as overall coefficient at means.
Marginal effects calculated at means of all variables except *Driller scale*, which is held at its median.
Driller scale and *Recent contracts* are treated as endogenous in IV specifications.
*** $p < .01$, ** $p < .05$, * $p < .10$.

coefficients from the linear IV regressions cannot be directly compared to the discrete choice models from previous tables. Note that all of the basic results from the earlier regressions are preserved: the probability of employing a turnkey contract decreases with repeated interaction, increases for exploratory wells, decreases with water depth for development wells, decreases in E&P company scale, and increases in driller scale. In addition, the effect of repeated interaction is significantly more pronounced for exploratory wells, as in previous regressions. It should be noted that the estimated marginal effects from these linear regressions also turn out to be comparable to the effects computed in earlier tables.

Columns (ii) and (iv) present the corresponding instrumental variables regressions. The basic qualitative results described above persist in both cases. However, in both cases, instrumenting for *recent contracts* and *driller scale* makes the coefficient on repeated interaction more negative. The difference in magnitudes is not large, suggesting that perhaps endogeneity is not a significant problem here. However, a Hausman test (Hausman, 1978; Wooldridge, 2002: 118–122) rejects the exogeneity of *recent contracts* and *driller scale* at a p-value of 2%. Thus the small differences in coefficient magnitude may simply reflect that the two sources of bias discussed above were largely canceling each other out.

5.2.3 Validity of the Instruments. The analysis of Section 5.2 is all conditional on the validity of our instruments. As reported earlier, the instruments do have significant predictive power. However, one could challenge whether they are properly excluded from the contract choice equation (or, more precisely, whether they are truly uncorrelated with the contract choice error). In this section we consider two potential sources of correlation between *recent contracts* and the contract choice error.

First, there may be unobserved (to us as econometricians) characteristics of the geographic subregion that create a longer-run endogenous matching problem of drillers to subregion. For example, a subregion might have characteristics that create severe incentive problems. Drillers with high levels of *recent contracts* might then locate rigs in the region in anticipation of bidding for future contracts with E&P companies they have worked with before and who are active in that region. In this case, *recent contracts* would reflect unobserved subregion characteristics that would *not* be properly excluded from the contract choice equation but would be part of that equation's error. To address this, we repeated the analysis including fixed effects for each geographic subregion, which eliminates unobserved subregion characteristics from the contract choice equation's error term. Our main results continue to hold; in particular, the coefficient on *recent contracts* is negative and significant when the IV specifications of Table 6 are modified to include subregion fixed effects (−0.0080, significant at 10% for the augmented version of column (ii); −0.0119, significant at 5% for the augmented version of column (iv)).

Second, it may be that an E&P's incentive to abide by an unwritten agreement supported by repeated interaction is adversely affected by the presence of other drillers with high levels of *recent contracts*. In this case, the value of the repeated interaction with the winning driller is undermined by the presence of nonwinning drillers in the region who also interact frequently with the E&P and provide a good alternative should the E&P behave opportunistically with respect to the winning driller. This suggests that a high average level of repeated interaction in a region (one of our instruments) could be correlated with the contract choice equation's error if, for example, this increased incentive to cheat led to more or less use of turnkey contracting (depending on which form you believe provides better protection to the driller). We are unable to test for this possibility since it is a maintained assumption of our instrumental variables estimation that the E&P takes into account the frequency of its interaction with only the winning driller in making its choice of contract form.

6. Conclusion

Fixed-price and cost-plus contracts embody a trade-off between contracting costs and incentive problems. We argue that repeated interaction may help to solve either of these problems and may therefore serve as either a substitute or complement for high-powered (fixed-price) formal contracts, depending on which problem they mitigate more effectively. Our empirical analysis shows that, in the offshore drilling industry, more frequent interaction leads to greater adoption of day-rate contracts (which have poorer incentives but lower contracting costs), suggesting that repeated interaction works primarily to mitigate incentive problems and therefore act as substitutes for strong formal contracts. This finding becomes even more pronounced when instrumental variables are used to account for simultaneity and endogenous matching of drillers to projects.

There remain a number of questions that we have not addressed in this article, which should provide fruitful areas for future research. Here we have considered only the E&P company's static problem of contract and driller choice, but not the dynamic effects these choices have on future contracts. More generally, we should view the driller selection process as a combination of making the optimal choice for the current project and deliberately cultivating repeated interaction with particular drillers for long-run benefit. In addition, E&P companies may choose to interact repeatedly with a set of several drillers in order to compare their performance or in order to ameliorate holdup problems by preserving alternatives. Understanding the dynamics of contractor choice remains an open area of research.

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