Strategic Decision-Making with Information and Extraction Externalities:
A Structural Model of the Multi-Stage Investment Timing Game
in Offshore Petroleum Production

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1 Appendix: Monte Carlo experiments

To assess the finite sample distribution of the estimators, Table A-1 presents the results from two Monte Carlo experiments. In each experiment, I run 100 simulations of 87 markets each for a given set of fixed parameters.[1] To generate the simulated data, the Markov perfect equilibrium is first computed for the given set of parameters using dynamic programming. The exploration and development policy functions arising from the equilibrium are then used in conjunction with the empirical transition matrix for the exogenous variables and with random draws, with replacement, from the empirical distribution of initial conditions to simulate sample paths for each of 87 markets to form a simulated panel data set. Finally, the structural econometric model is run on each of the 100 simulated panels to obtain the finite sample distribution of the estimators.

In experiment (1), the parameters are chosen so that neighbors have a large, negative effect and so that private information plays a small role in the exploration decision and a moderate role in the development decision. In particular, the relative importance of a neighbor's exploration decision as a fraction of a firm's average development cost is given by $\frac{\gamma_{tote}}{\left|\gamma_{drill}\cdot\overline{drill\_\ cost_t}\right|} = \frac{\gamma_{tote}}{0.49|\gamma_{drill}|} = -1.36$. Similarly, the relative importance of a neighbor's development decision as a fraction of a firm's average development cost is given by $\frac{\gamma_{totd}}{\left|\gamma_{drill}\cdot\overline{drill\_\ cost_t}\right|} = \frac{\gamma_{totd}}{0.49|\gamma_{drill}|} = -1.59$. Thus, when a neighbor explores or develops, this decreases profits by more than mean development costs. In terms of private information, the mean pre-exploration shock is only a small fraction of the mean exploration costs: $\frac{\sigma_\mu}{\overline{c^e(\Omega_{kt};\theta)}} = \frac{\sigma_\mu}{-\alpha\cdot\left(\overline{drill\_\ cost_t}+1\right)} = \frac{\sigma_\mu}{-1.49\alpha} = 0.08$. The mean pre-development shock is only a moderate fraction of mean development costs : $\frac{\sigma_\varepsilon}{\left|\gamma_{drill}\cdot\overline{drill\_\ cost_t}\right|} = \frac{\sigma_\varepsilon}{0.49|\gamma_{drill}|} = 0.91$. According to results of the first experiment, with the exception of the parameters of the distribution of private information, the estimators appear to recover the actual parameter values fairly well.

In experiment (2), the parameters are chosen so that neighbors have a small, positive effect and so that private information plays a large role in both the exploration and development decisions. In particular, the relative importance of a neighbor's exploration decision is a small fraction of a firm's development costs: $\frac{\gamma_{tote}}{\left|\gamma_{drill}\cdot\overline{drill\_\ cost_t}\right|} = \frac{\gamma_{tote}}{0.49|\gamma_{drill}|} = 0.51$. The relative importance of a neighbor's development decision is

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[1] I chose to simulate 87 markets because there are 87 markets in my actual data set.

also a small fraction of a firm's costs: $\frac{\gamma_{totd}}{\left|\gamma_{drill}\cdot\overline{drill\_\,cost_t}\right|} = \frac{\gamma_{totd}}{0.49|\gamma_{drill}|} = 0.26$. In terms of private information, the mean pre-exploration shock is over two and a half times the mean exploration costs: $\frac{\sigma_\mu}{\overline{c^e(\Omega_{kt};\theta)}} = \frac{\sigma_\mu}{-\alpha\cdot\left(\overline{drill\_\,cost_t}+1\right)} = \frac{\sigma_\mu}{-1.49\alpha} = 2.68$. The mean pre-development shock is nearly four times mean development costs : $\frac{\sigma_\varepsilon}{\left|\gamma_{drill}\cdot\overline{drill\_\,cost_t}\right|} = \frac{\sigma_\varepsilon}{0.49|\gamma_{drill}|} = 3.82$. According to results of the second experiment, the estimators appear to recover the actual parameter values fairly well. Because the variances σ_μ^2 and σ_ε^2 of the distribution of the stochastic shocks are larger than in the first experiment, the standard deviations are larger as well, as expected.

Thus, results from both Monte Carlo experiments indicate that, with the exception of the parameters of the distribution of private information in experiment (1), the estimators recover the actual parameter values fairly well.

To analyze the effect of a state variable that is observed by the firms when they make their decisions but unobservable to the econometrician (i.e., a common shock), two additional Monte Carlo experiments are run. Using the sets of parameters used in the two experiments above, data are generated with a common shock that takes on the values -1, 0 and 1 with equal probability. The estimation procedure is then run on the data without knowledge of the common shocks. As seen in Table A-2, the results from both experiments indicate that the estimators recover the actual parameter values fairly well, even though the common shock is not observed by the econometrician. The bias introduced by the common shock is therefore small. This is consistent with Pakes et al. (2007), who find that the bias from serially correlated common shocks is small.

Spatially correlated unobservables are also addressed by Lin (2009), who analyzes strategic interactions during the exploration stage of petroleum production using instrumental variables to address endogeneity due to simultaneity and to spatially correlated unobservables. A reduced-form discrete response model of a firm's exploration timing decision that uses variables based on the timing of a neighbor's lease term as instruments for the neighbor's decision is employed. Consistent with the results of this paper, Lin (2009) finds that there are no net strategic interactions during exploration.

TABLE A-1. Monte Carlo results

	(1)			(2)		
	True value	Mean	Standard Deviation	True value	Mean	Standard Deviation
σ_μ	1	2.17	0.14	40	40.00	0.00
σ_ε	4	4.25	0.03	15	14.01	1.41
coefficient α in the exploration profit function on:						
discretized real drilling cost + 1	-8	-7.70	0.04	-10	-10.00	0.01
coefficients γ in the development profit function on:						
other tract in market has been explored (dummy)	-6	-6.00	0.00	2	1.81	0.22
other tract in market has been developed (dummy)	-7	-7.00	0.00	1	0.93	0.08
discretized average winning bid per acre	8	8.00	0.00	5	4.97	0.02
discretized real drilling cost	-9	-9.00	0.00	-8	-8.00	0.01
discretized real oil price	10	10.00	0.00	5	4.98	0.01
constant	11	11.00	0.00	-15	-15.06	0.03

Notes: Results are from 100 simulations of 87 markets each.

TABLE A-2. Monte Carlo results for common shock analysis

	(1) True value	Mean	Standard Deviation	(2) True value	Mean	Standard Deviation
σ_{μ}	1	1.00	0.00	40	40.00	0.00
σ_{ε}	4	4.00	0.00	15	13.72	1.95
coefficient α in the exploration profit function on:						
discretized real drilling cost + 1	-8	-8.00	0.00	-10	-10.00	0.01
coefficients γ in the development profit function on:						
other tract in market has been explored (dummy)	-6	-6.00	0.00	2	1.75	0.30
other tract in market has been developed (dummy)	-7	-7.00	0.00	1	0.91	0.12
discretized average winning bid per acre	8	8.00	0.00	5	4.96	0.04
discretized real drilling cost	-9	-9.00	0.00	-8	-8.01	0.01
discretized real oil price	10	10.00	0.00	5	4.98	0.02
constant	11	11.00	0.00	-15	-15.08	0.06

Notes: Results are from 100 simulations of 87 markets each. Data are generated with a common shock that takes on the values -1, 0 and 1 with equal probability. The estimation procedure is then run on the data without knowledge of the common shocks.