The Dynamic Efficiency Costs of Common-Pool Resource Exploitation

Ling Huang and Martin D. Smith

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Online Appendix

Proposition: Compute $u_i(a_i = 1, \mathbf{s}, \xi_i; \boldsymbol{\theta})$

In $u_i(a_i = 1, \mathbf{a}_{-i}, \mathbf{s}, \xi_i; \boldsymbol{\theta})$, except $Tvessel$, other part of utility does not depend on other fishermen's actions.

$$\begin{aligned}\sum_{\mathbf{a}_{-i}} Tvessel * \sigma_{-i}(\mathbf{a}_{-i}|\mathbf{s}) &= 1 + \sum_{j\neq i} a_j * \sigma_j(a_j|\mathbf{s}) \\ &= 1 + \sum_{j\neq i} 1\{a_j = 1\} * \sigma_j(a_j|\mathbf{s}) \\ &= 1 + \sum_{j\neq i} \sigma_j(a_j = 1|\mathbf{s})\end{aligned}$$

$$\begin{aligned}\sum_{\mathbf{a}_{-i}} Tvessel^2 * \sigma_{-i}(\mathbf{a}_{-i}|\mathbf{s}) &= \sum_{\mathbf{a}_{-i}} (\sum a_j)^2 * \sigma_{-i}(\mathbf{a}_{-i}|\mathbf{s}) \\ &= \sum_{\mathbf{a}_{-i}} (1 + 2\sum_{j\neq i} a_j + \sum_{j\neq i} a_j^2 + \sum_{j\neq k, j,k\neq i} a_j * a_k)\sigma_{-i}(\mathbf{a}_{-i}|\mathbf{s}) \\ &= 1 + 3\sum_{j\neq i} \sigma_j(a_j = 1|\mathbf{s}) + \sum_{j\neq k, j,k\neq i} \sigma_j(a_j = 1|\mathbf{s})\sigma_j(a_k = 1|\mathbf{s})\end{aligned}$$

Then

$$\begin{aligned}&u_i(a_i = 1, \mathbf{s}, \xi_i; \boldsymbol{\theta}) = \alpha Price * q_i * e^W * X \\ &* [1 + \gamma + \frac{\gamma^2}{2} + (\gamma + \frac{3\gamma^2}{2}) \sum_{j\neq i} \sigma_j(a_j = 1|\mathbf{s}) + \frac{\gamma^2}{2} \sum_{j\neq k, j,k\neq i} \sigma_j(a_j = 1|\mathbf{s})\sigma_k(a_k = 1|\mathbf{s})] \\ &- \boldsymbol{\beta}'\mathbf{S} + \xi_i\end{aligned}$$

Table 1: Augmented Dickey–Fuller Unit Root Tests

Type	Rho	Pr<Rho	Tau	Pr<Tau	F	Pr>F
Shrimp price						
W/O Drift & Trend	-52.0167	<.0001	-4.59	<.0001		
Drift	-397.441	0.0001	-13.37	<.0001	89.60	0.0010
Trend	-710.034	0.0001	-17.66	<.0001	156.05	0.0010
WSPD						
W/O Drift & Trend	-67.7090	<.0001	-5.80	<.0001		
Drift	-2651.05	0.0001	-36.34	<.0001	660.33	0.0010
Trend	-2702.34	0.0001	-36.69	<.0001	672.98	0.0010
WVHT						
W/O Drift & Trend	-1013.70	0.0001	-22.75	<.0001		
Drift	-1138.93	0.0001	-24.05	<.0001	289.24	0.0010
Trend	-1153.03	0.0001	-24.21	<.0001	293.01	0.0010
Diesel Price						
W/O Drift & Trend	0.1063	0.7077	0.85	0.8930		
Drift	-2.2694	0.7460	-0.68	0.8498	0.61	0.9186
Trend	-7.4733	0.6245	-1.77	0.7183	2.26	0.7245

Note: Depicts the results of Augmented Dickey-Fuller tests. For each state variable, three different models are tested with one lag of the response variable. The first line "W/O Drift & Trend" is that of the random walk without drift and without trend. "Rho" is the coefficient of the lagged response variables, while "Tau" is the test statistic for whether the response series is non-stationary.

Table 2: Dynamics of Shrimp Price, Wind Speed, Wave Height, and Stock Shocks

Parameter	Description	Coefficient	Standard Error
	Shrimp Price*		
Intercept		0.16331	(0.00819)
Lag(log(price))	One day lagged of logged shrimp price	0.75188	(0.01148)
	Wave Speed*		
Intercept		1.088944	(0.025376)
lag(log(WSPD))	One day lagged of logged wind speed	0.406951	(0.013396)
	Wave Height*		
Intercept		0.039297	(0.006237)
lag(log(WVHT))	One day lagged of logged wave height	0.693213	(0.010822)
Cross Model Cov.	log(WSPD)	log(WVHT)	
log(WSPD)	0.129154	0.071702	
log(WVHT)	0.071702	0.119709	
Cross Model Corr.	log(WSPD)	log(WVHT)	
log(WSPD)	1.00000	0.57665	
log(WVHT)	0.57665	1.00000	
	ζ_t (Daily fixed effect)		
ζ_{t-1}	lag of ζ_t	0.72201	(0.02711)

*Note: Reports the results from the Autoregressive (AR) model fitted to shrimp price, wind speed and wave height. Wind speed and wave height may be highly correlated with each other, so a Seemingly Unrelated Regressions (SUR) model is used to recover their data generating processes simultaneously.

Table 3: Dynamics of Diesel Price

Variable	Coefficient	F Value	Pr > F
Bspline.week_0	122.77	1330.23	<.0001
Bspline.week_1	168.06	1576.53	<.0001
Bspline.week_2	141.61	1181.43	<.0001
Bspline.week_3	142.41	1894.59	<.0001
Bspline.week_4	140.93	2145.33	<.0001
Bspline.week_5	168.68	3184.24	<.0001
Bspline.week_6	161.49	3282.77	<.0001
Bspline.week_7	136.86	2177.36	<.0001
Bspline.week_8	143.87	2317.98	<.0001
Bspline.week_9	132.77	2037.22	<.0001
Bspline.week_10	139.37	2316.21	<.0001
Bspline.week_11	113.87	1498.78	<.0001
Bspline.week_12	107.81	1344.34	<.0001
Bspline.week_13	134.45	2161.88	<.0001
Bspline.week_14	112.34	1473.39	<.0001
Bspline.week_15	144.03	2404.91	<.0001
Bspline.week_16	122.93	1748.57	<.0001
Bspline.week_17	161.38	3013.60	<.0001
Bspline.week_18	163.15	3085.95	<.0001
Bspline.week_19	122.27	1745.30	<.0001
Bspline.week_20	145.64	2536.57	<.0001
Bspline.week_21	133.22	2053.32	<.0001
Bspline.week_22	148.13	2538.56	<.0001
Bspline.week_23	146.64	2571.54	<.0001
Bspline.week_24	157.68	2902.32	<.0001
Bspline.week_25	151.93	2674.75	<.0001
Bspline.week_26	218.61	5520.25	<.0001
Bspline.week_27	162.98	3054.99	<.0001
Bspline.week_28	199.89	4534.88	<.0001
Bspline.week_29	204.00	4516.93	<.0001
Bspline.week_30	196.05	3596.14	<.0001
Bspline.week_31	318.42	5977.06	<.0001
Bspline.week_32	184.63	1902.91	<.0001
Bspline.week_33	224.78	4459.02	<.0001
Observation	313		
R-square	0.985		
Adj. R-square	0.983		

Note: Cubic b-splines with degree=3 and knots=30 are estimated.

Table 4: Conditional Choice Probability

Variables	Coefficient	(Standard Error)
constant	-19.7419	(0.6361)
Shrimp price	3.0774	(0.1462)
Shrimp price^2	-0.6834	(0.0270)
Shrimp price^3	0.0306	(0.00144)
stock	0.1110	(0.00869)
stock^2	0.00223	(0.000265)
stock^3	-0.000047	(2.86E-6)
Diesel price	0.1534	(0.00843)
Diesel price^2	-0.00077	(0.000043)
Diesel price^3	1.195E-6	(7.334E-8)
Weekend(1 if weekend)	-0.9464	(0.0112)
Shrimp price*stock	-0.0151	(0.00125)
Shrimp price*Diesel price	-0.00277	(0.000450)
stock*Diesel price	-9.24E-6	(0.000031)
Shrimp price*q	0.6656	(0.0122)
stock*len	0.000837	(0.000029)
WSPD	-0.0958	(0.0213)
WSPD^2	0.0108	(0.00297)
WSPD^3	-0.00033	(0.000125)
WVHT	0.0839	(0.0386)
WVHT^2	-0.1148	(0.0165)
WVHT^3	0.00913	(0.00164)
Season closure(1 if open)	0.6886	(0.0183)
q*WSPD	-0.0179	(0.0108)
q*WVHT	-0.0201	(0.0108)
ζ_t	0.1655	(0.00728)

Note: Reports results from a flexible logit model to estimate the fishing decision probabilities. Here, "stock" is the deterministic part of the stock index X in the model.

Table 5: Profit structure estimated from partial data (years 2000-2004 with 2005 as hold out year)

Parameter	Description	Scale	Coefficient	(Standard Error)
revenue	Shrimp price*Harvest	1000 dollars	1.39	(0.024)
wspd	Wind speed	1 m/s	-0.09	(0.003)
wvht	Wave height	1 meter	-0.16	(0.015)
diesel	Diesel price	1 dollars	-0.03	(0.000)
Weekend	Saturday or Sunday	1	-0.83	(0.008)
stock	stock size	1 stock index unit	0.07	(0.000)
len	Vessel length	10 feet	-0.43	(0.010)
len^2	Vessel length squared	100	-0.06	(0.002)
len_wspd	Length*Wind speed	100	0.08	(0.007)
len_wvht	Length*Wave height	100	0.10	(0.030)
len_diesel	Length*diesel	100	0.05	(0.001)
har	Harvest	1000 pounds	-2.19	(0.122)
har_len	Harvest*length	10,000	0.82	(0.024)
har^2	Harvest squared	1E+6	-5.64	(0.109)

Table 6: Profit structure for each iteration pseudo-NPL method

Parameter	Scale	Second iteration	Third iteration	Fourth iteration	Fifth iteration	Sixth iteration
revenue	1000 dollars	1.20	1.15	1.14	1.14	1.14
		(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
wspd	1 m/s	-0.15	-0.15	-0.15	-0.15	-0.15
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
wvht	1 meter	-0.27	-0.25	-0.24	-0.24	-0.24
		(0.01	(0.01)	(0.01)	(0.01)	(0.01)
diesel	1 dollars	-0.02	-0.02	-0.02	-0.02	-0.02
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Weekend	1	-0.84	-0.84	-0.84	-0.84	-0.84
		(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
stock	1 index unit	0.06	0.06	0.06	0.06	0.06
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
len	10 feet	-0.29	-0.30	-0.30	-0.30	-0.30
		(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
len^2	100	-0.04	-0.04	-0.03	-0.03	-0.03
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
len_wspd	100	0.13	0.13	0.13	0.13	0.13
		(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
len_wvht	100	0.40	0.40	0.40	0.40	0.40
		(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
len_diesel	100	0.02	0.02	0.02	0.02	0.02
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
har	1000 pounds	-0.69	-0.48	-0.43	-0.41	-0.41
		(0.11)	(0.11)	(0.11)	(0.11)	(0.11)
har_len	10,000	0.59	0.57	0.56	0.55	0.55
		(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
har^2	1E+6	-4.80	-4.70	-4.66	-4.65	-4.65
		(0.09)	(0.09)	(0.09)	(0.09)	(0.09)
Euclidean distance to previous iteration		1.0303	0.2323	0.0685	0.0188	0.0038

Note: Standard errors are in parenthesis. The first-stage simulation-based CCP estimator provides the decision rule; the second-stage PML reveals the profit structure. Using second-stage PML results, we can calculate the probabilities for all observed state variables. Then we regress the probability on a flexible function of state variables. Based on this function, we can repeat the first-stage simulation based CCP estimation again, which starts the second round. PML is again applied to obtain the new profit structure and then the new updated probability, and so on. Altogether we have done six iterations.

Table 7: Efficiency Gains in the North Carolina Shrimp Fishery Using the Sixth Iteration Pseudo-NPL with a 7% Annual Discount Rate

year	Observed revenue*(OR) (10^6)	Status Quo rent without deducting the cost of capital (SQR) (10^6)	SQR / $\overline{OR}$	Efficiency gains due to the allocated entry system(E1)(10^6)	E1 / $\overline{OR}$	E1 / $\overline{SQR}$	Efficiency gains if removing congestion (E2)(10^6)	E2 / $\overline{OR}$
2000	18.19	8.20	45%	2.86	16%	35%	-0.71	-4%
2001	8.91	3.39	38%	0.30	3%	9%	0.32	4%
2002	13.68	9.57	70%	6.90	50%	72%	-1.80	-13%
2003	8.26	5.22	63%	2.29	28%	44%	-0.44	-5%
2004	6.63	2.11	32%	0.36	5%	17%	0.07	1%
2005	2.48	0.78	32%	0.41	16%	52%	0.02	1%
Average	9.69	4.88	50%	2.18	23%	45%	-0.43	-4%

year		Efficiency gains due to season closure policy (E3)(10^6)	E3 / $\overline{OR}$	Efficiency gains due to strict season closure policy (E4)(10^6)	E4 / $\overline{OR}$			
2000		0.69	4%	0.64	4%			
2001		0.02	0%	0.07	1%			
2002		0.37	3%	0.96	7%			
2003		0.17	2%	0.14	2%			
2004		0.03	0%	0.02	0%			
2005		-0.01	0%	0.01	1%			
Average		0.21	2%	0.31	3%			

*For active vessels only

Table 8: Efficiency Gains in the North Carolina Shrimp Fishery with an 17% Annual Discount Rate

year	Observed revenue*(OR) (10^6)	Status Quo rent without deducting the cost of capital (SQR) (10^6)	SQR / $\overline{OR}$	Efficiency gains due to the allocated entry system(E1)(10^6)	E1 / $\overline{OR}$	E1 / $\overline{SQR}$	Efficiency gains if removing congestion (E2)(10^6)	E2 / $\overline{OR}$
2000	16.98	6.40	38%	2.06	12%	32%	-0.73	-4%
2001	8.33	2.50	30%	0.25	3%	10%	0.19	2%
2002	12.81	6.90	54%	5.53	43%	80%	-1.63	-13%
2003	7.72	3.67	48%	1.98	26%	54%	-0.50	-6%
2004	6.17	1.57	25%	0.33	5%	21%	-0.01	-0%
2005	2.32	0.61	26%	0.39	17%	64%	-0.01	-0%
Average	9.05	3.61	40%	1.76	19%	49%	-0.45	-5%

year		Efficiency gains due to season closure policy (E3)(10^6)	E3 / $\overline{OR}$	Efficiency gains due to strict season closure policy (E4)(10^6)	E4 / $\overline{OR}$			
2000		0.52	3%	0.46	3%			
2001		0.01	0%	0.06	1%			
2002		0.27	2%	0.61	5%			
2003		0.11	1%	0.09	1%			
2004		0.02	0%	0.00	0%			
2005		-0.02	-1%	0.00	0%			
Average		0.15	2%	0.20	2%			

*For active vessels only

Table 9: Efficiency Gains in the North Carolina Shrimp Fishery with a 0% Annual Discount Rate

year	Observed revenue*(OR) (10^6)	Status Quo rent without deducting the cost of capital (SQR) (10^6)	SQR / $\overline{OR}$	Efficiency gains due to the allocated entry system(E1)(10^6)	E1 / $\overline{OR}$	E1 / $\overline{SQR}$	Efficiency gains if removing congestion (E2)(10^6)	E2 / $\overline{OR}$
2000	19.05	7.10	37%	2.37	12%	33%	-0.81	-4%
2001	9.32	2.80	30%	0.29	3%	10%	0.21	2%
2002	14.29	7.61	53%	6.31	44%	83%	-1.80	-13%
2003	8.64	4.08	47%	2.25	26%	55%	-0.55	-6%
2004	6.95	1.75	25%	0.38	5%	21%	-0.01	-0%
2005	2.60	0.69	26%	0.46	18%	67%	-0.01	-0%
Average	10.14	4.00	39%	2.01	20%	50%	-0.50	-5%

year		Efficiency gains due to season closure policy (E3)(10^6)	E3 / $\overline{OR}$	Efficiency gains due to strict season closure policy (E4)(10^6)	E4 / $\overline{OR}$			
2000		0.58	3%	0.52	3%			
2001		0.01	0%	0.07	1%			
2002		0.30	2%	0.68	5%			
2003		0.13	1%	0.10	1%			
2004		0.02	0%	0.00	0%			
2005		-0.02	-1%	0.00	0%			
Average		0.17	2%	0.23	2%			

*For active vessels only