Distortive Institutions, Strategic Behavior, and Groundwater Demand

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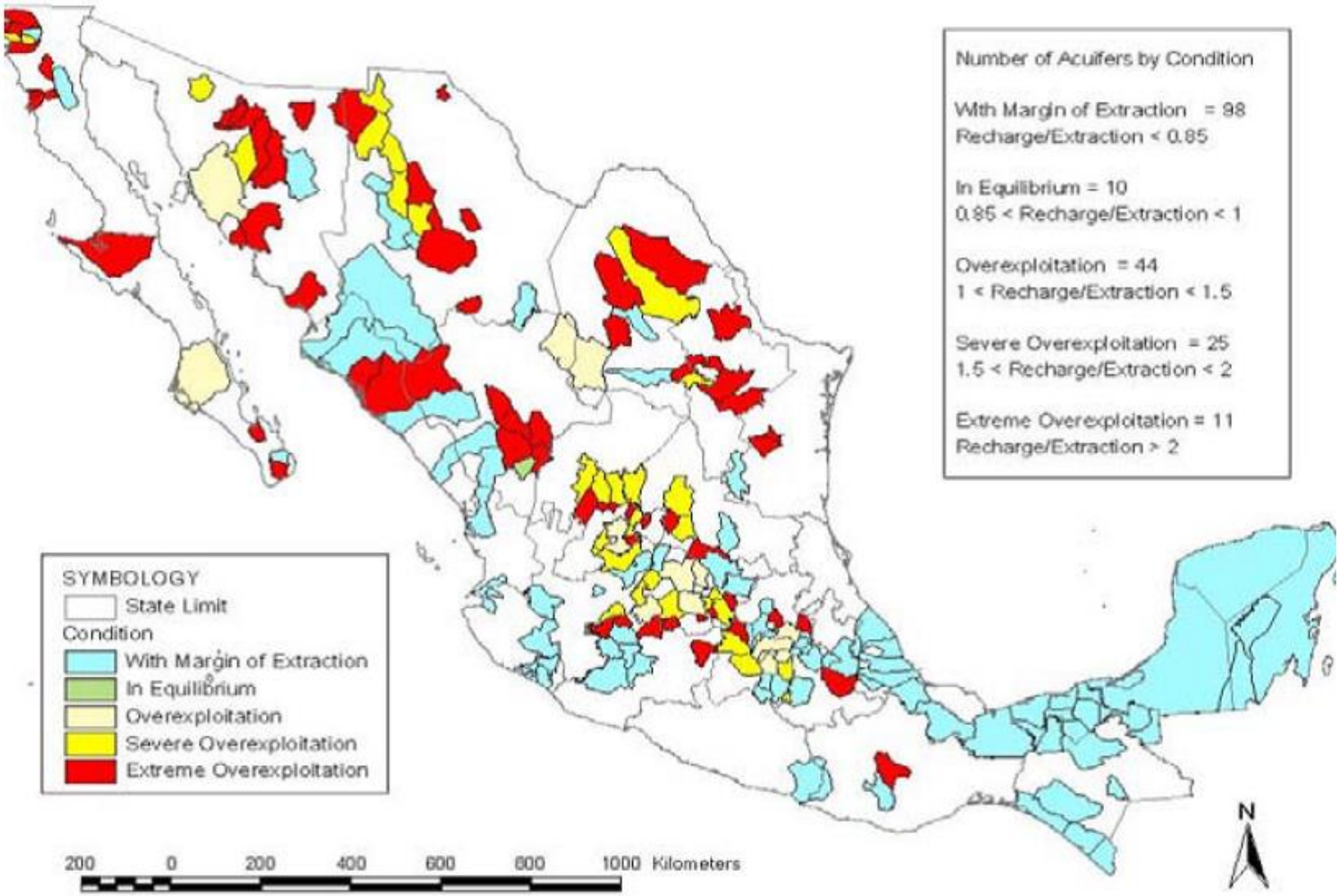
Background: Groundwater Depletion in Mexico



Previous Literature – Theory/Empirics

- Theory – inefficiency due to externality in groundwater pumping (cost externality)

- Theory – inefficiency due to strategic behavior (strategic externality)

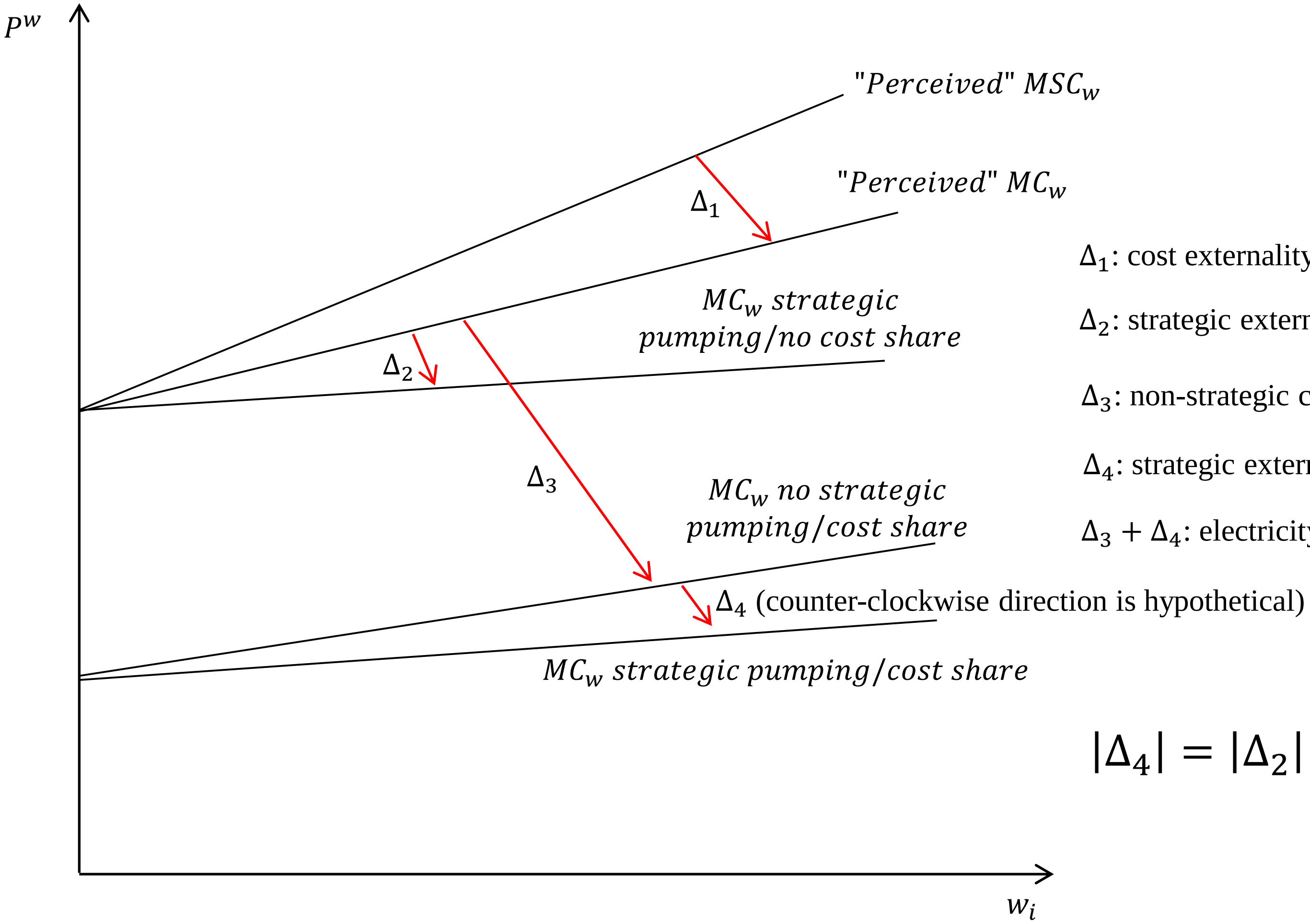
- The theoretical literature analyzing strategic pumping (Dixon, 1989; Negri, 1989; Provencher and Burt, 1993; Rubio and Casino, 2003) assumes irrigators hold Bertrand conjectures
  - Expects to "crowd out" other irrigators

- Empirical evidence weakly supports theoretical predictions
  - Pfeiffer and Lin (2012) in Kansas
  - Huang et al. (2013) in China
  - Savage and Brozović (2011) in Nebraska

Externalities in Mexico

- Cost and strategic externalities likely strong
  - Farmers share the same well
- Further distortions to MPC from electricity subsidies
- Electricity cost-sharing: an unexamined source of externality
  - Effect
  - Interaction with other externalities
- Welfare-ranking of policies – shadow price – structural model
- We estimate structural model of pumping
  - Strategic interactions accommodated by “importing” structural approach from NEIO.
  - We extend this approach to incorporate cost-sharing rules.

Interpretation of Results



Δ_1: cost externality

Δ_2: strategic externality

Δ_3: non-strategic cost-share externality

Δ_4: strategic externality under cost-share

$\Delta_3 + \Delta_4$: electricity cost-share externality

$$|\Delta_4| = |\Delta_2|$$

Model of Water Demand

- Farmer’s problem is:

$\min_{w_k^i}\left\{C(p_x, y_{ik}^*, w_k^i, L_k^i, z_k^i) + P^W_{k,\theta_k} w_k^i\right\}$, were y_{ik}^* equalizes output price and mg cost

- First Order Condition for water (after re-arrangement):

$$AWC_k\left\{\theta_k\left[1+\varepsilon_k\overbrace{\left(1+\lambda_k^i\right)}^{\textit{strategic externality}}\right]+\theta_{k,e}[1+\varepsilon_k]\frac{1}{N_k}\frac{W_k}{w_k^i}\left[1+\lambda_k^i\right]+\theta_{k,a}[1+\varepsilon_k]\frac{L_k^i}{L_k}\frac{W_k}{w_k^i}\left[1+\lambda_k^i\right]\right\}=-C_{w_{ik}}$$

Share of electricity paid to share of water consumed
Reduces AC of relatively water-intensive producers

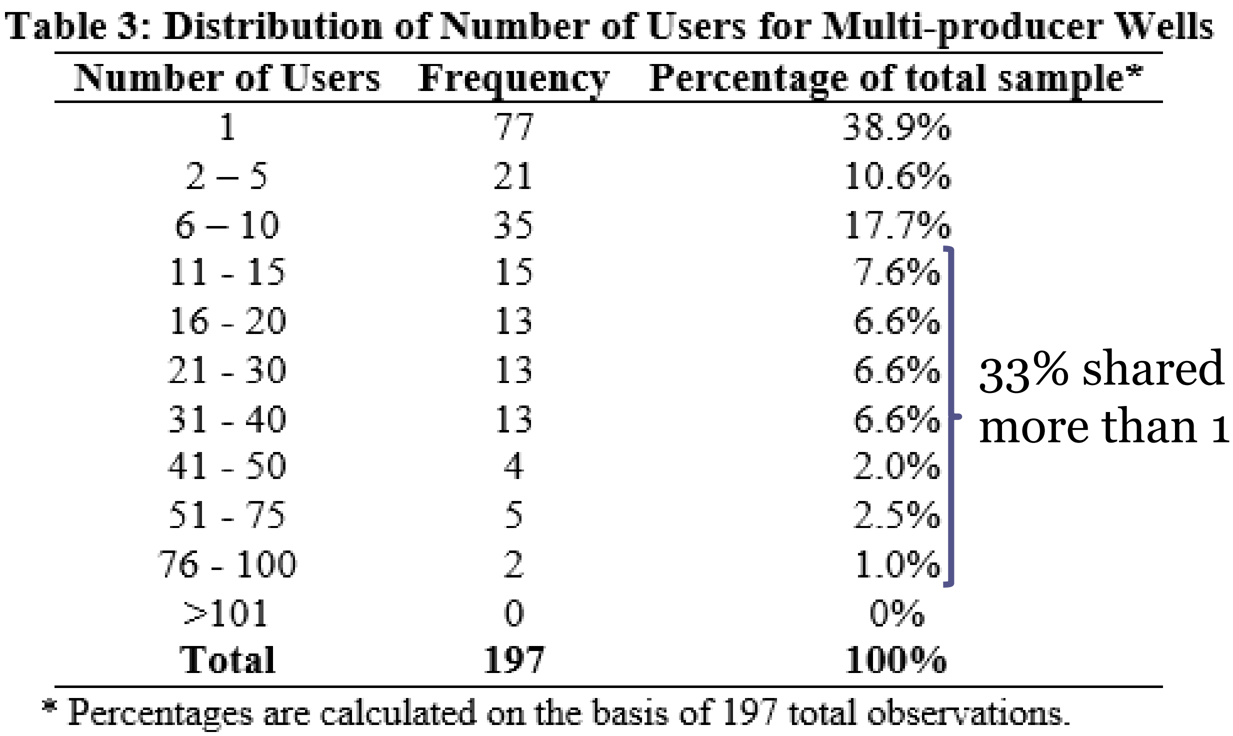


Table 3: Distribution of Number of Users for Multi-producer Wells

Number of Users	Frequency	Percentage of total sample*
1	77	38.9%
2 – 5	21	10.6%
6 – 10	35	17.7%
11 - 15	15	7.6%
16 - 20	13	6.6%
21 - 30	13	6.6%
31 - 40	13	6.6%
41 - 50	4	2.0%
51 - 75	5	2.5%
76 - 100	2	1.0%
>101	0	0%
Total	**197**	**100%**

* Percentages are calculated on the basis of 197 total observations.

33% shared by
more than 10 farmers

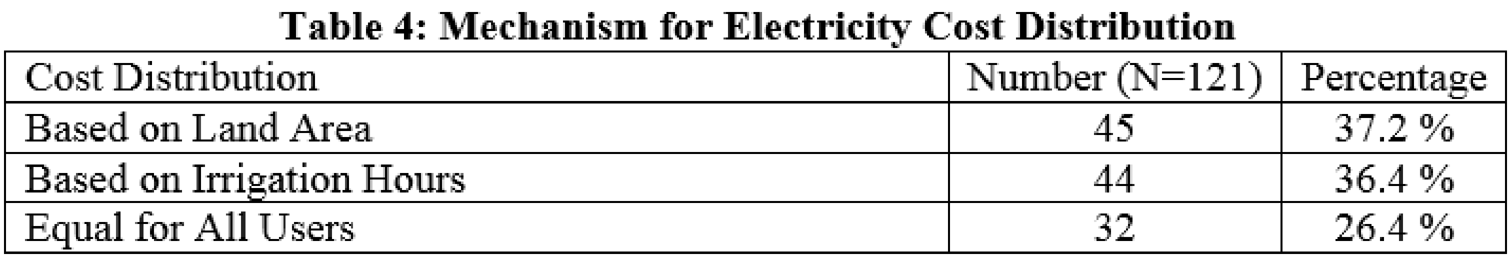


Table 4: Mechanism for Electricity Cost Distribution

Cost Distribution	Number (N=121)	Percentage
Based on Land Area	45	37.2 %
Based on Irrigation Hours	44	36.4 %
Equal for All Users	32	26.4 %

Econometric Model - system

- Restricted Generalized Leontief cost function
  - Flexible and satisfies curvature conditions under quasi-fixed inputs
- We estimate:
    - Two variable inputs: fertilizer and composite of others.
    - Output supply
    - First order condition for water
- (cross-section) Exogenous variables: land, soil infiltration, climate, and well’s drawdown.
- Water FOC results in a nonlinear model. A nonlinear system is estimated.
- A total of 35 parameters to be estimated.

Data

- Random selection from a national survey of irrigation wells
- Data on the 2002-2003 growing season
- Cross section of 197 wells.
- Farmer-crop-well level unit of observation.
  - Farmer may produce multiple crops, but single producer never uses multiple irrigation wells.
  - Includes cost share rule and share of electricity bill paid by farmer.
- Quantity and price of several inputs and outputs.
  - Aggregated according to Jorgenson's procedure for "exact" aggregation.

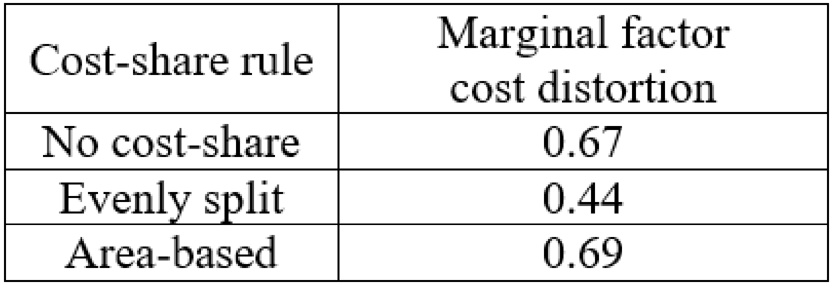
Data

- Socio-demographic information (e.g., age, family size, education).

- Choice of instruments – relevance and validity
  - Climatic variable, share of fruits and vegetables, soil infiltration

Results

- Conjectural variations:

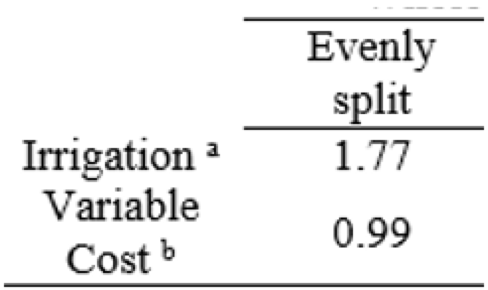


Cost-share rule	Marginal factor cost distortion
No cost-share	0.67
Evenly split	0.44
Area-based	0.69

- No Cost-Share - irrigators follow Bertrand-type conjectures
  - Consistent with Provencher and Burt, 1993 and Rubio and Casino, 2003.

- Electricity cost-sharing weakens Bertrand conjectures.
  - Farmers expect others will partially match their increase in pumping to keep marginal cost down.

Implications on Irrigation Application and Production Cost



	Evenly split
Irrigation [a]	1.77
Variable Cost [b]	0.99

a This row reports ratio of irrigation applied under cost-share to irrigation applied under no cost-share
b This row reports ratio of variable cost under cost-share to variable cost under no cost-share

- Big over-extraction – very little marginal benefit
- Elasticity of irrigation with respect to electricity price (average across sub-samples and cost-share mechanisms) is -0.03.

Policy Implications

- Elimination of cost-sharing rules seems the most cost-effective to reduce extraction.
- Elimination of electricity subsidy (or water pricing) may not be relatively cost-effective in reducing extraction.
- Integration among farmers not as cost-effective as elimination of cost-sharing rule

Thank you!!

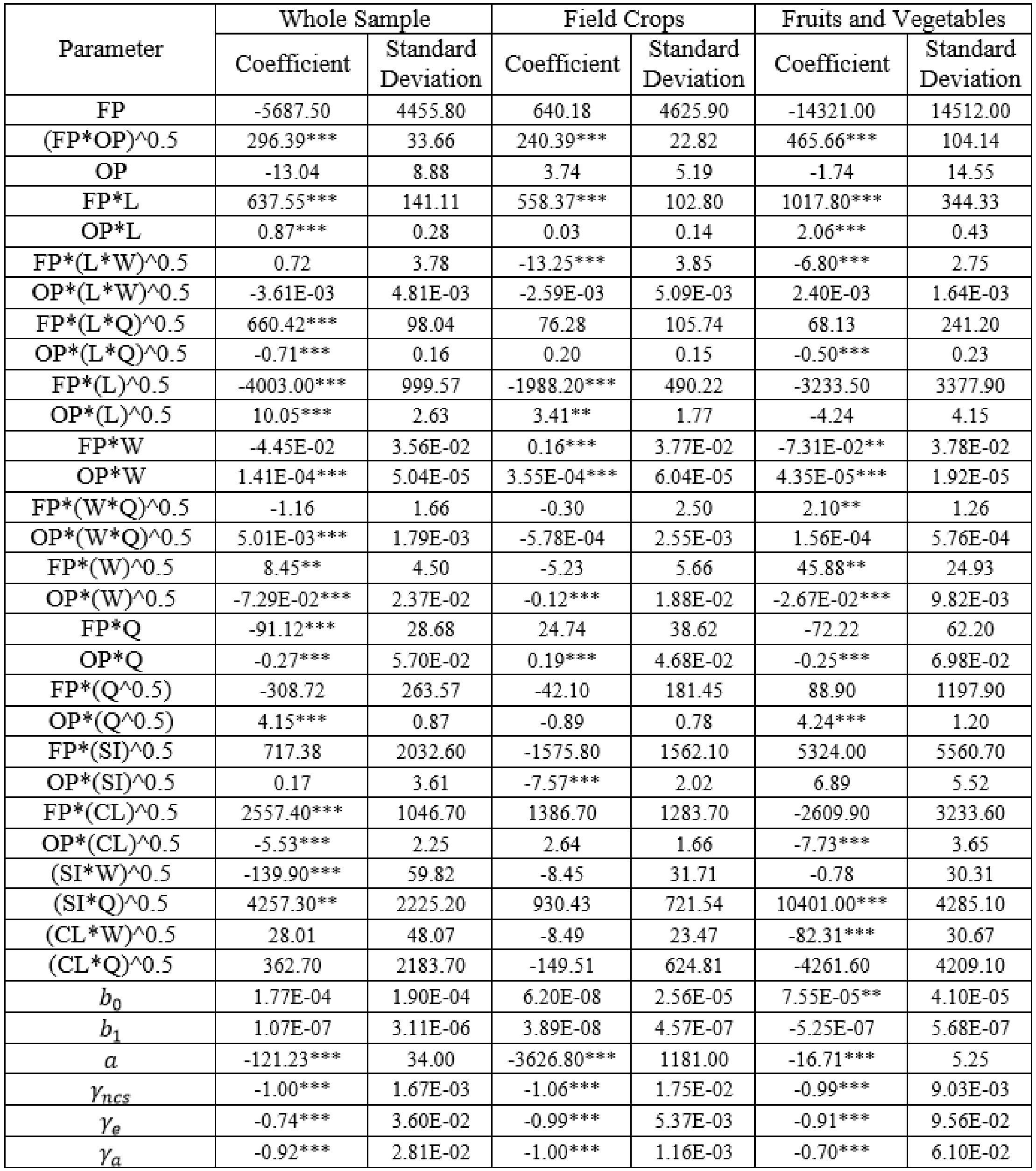
Q&A

Concluding Remarks

- Framework developed here allows testing for strategic over-extraction with electricity cost sharing rules
- Over-extraction from cost-share is partially compensated by conjecture on strategic complementarity
- Panel data would allow to better dissect all drivers of irrigation demand
  - Conduct parameters are not allowed to change across wells
  - They could also change in time (evolutionary game)

Extensions/Corrections

- Adjusting for Spatial correlation of errors.
- Disaggregate outputs and use a Tobin’s correction model for corner solutions.



Parameter	Whole Sample		Field Crops		Fruits and Vegetables	
	Coefficient	Standard Deviation	Coefficient	Standard Deviation	Coefficient	Standard Deviation
FP	-5687.50	4455.80	640.18	4625.90	-14321.00	14512.00
(FP*OP)^0.5	296.39***	33.66	240.39***	22.82	465.66***	104.14
OP	-13.04	8.88	3.74	5.19	-1.74	14.55
FP*L	637.55***	141.11	558.37***	102.80	1017.80***	344.33
OP*L	0.87***	0.28	0.03	0.14	2.06***	0.43
FP*(L*W)^0.5	0.72	3.78	-13.25***	3.85	-6.80***	2.75
OP*(L*W)^0.5	-3.61E-03	4.81E-03	-2.59E-03	5.09E-03	2.40E-03	1.64E-03
FP*(L*Q)^0.5	660.42***	98.04	76.28	105.74	68.13	241.20
OP*(L*Q)^0.5	-0.71***	0.16	0.20	0.15	-0.50***	0.23
FP*(L)^0.5	-4003.00***	999.57	-1988.20***	490.22	-3233.50	3377.90
OP*(L)^0.5	10.05***	2.63	3.41**	1.77	-4.24	4.15
FP*W	-4.45E-02	3.56E-02	0.16***	3.77E-02	-7.31E-02**	3.78E-02
OP*W	1.41E-04***	5.04E-05	3.55E-04***	6.04E-05	4.35E-05***	1.92E-05
FP*(W*Q)^0.5	-1.16	1.66	-0.30	2.50	2.10**	1.26
OP*(W*Q)^0.5	5.01E-03***	1.79E-03	-5.78E-04	2.55E-03	1.56E-04	5.76E-04
FP*(W)^0.5	8.45**	4.50	-5.23	5.66	45.88**	24.93
OP*(W)^0.5	-7.29E-02***	2.37E-02	-0.12***	1.88E-02	-2.67E-02***	9.82E-03
FP*Q	-91.12***	28.68	24.74	38.62	-72.22	62.20
OP*Q	-0.27***	5.70E-02	0.19***	4.68E-02	-0.25***	6.98E-02
FP*(Q^0.5)	-308.72	263.57	-42.10	181.45	88.90	1197.90
OP*(Q^0.5)	4.15***	0.87	-0.89	0.78	4.24***	1.20
FP*(SI)^0.5	717.38	2032.60	-1575.80	1562.10	5324.00	5560.70
OP*(SI)^0.5	0.17	3.61	-7.57***	2.02	6.89	5.52
FP*(CL)^0.5	2557.40***	1046.70	1386.70	1283.70	-2609.90	3233.60
OP*(CL)^0.5	-5.53***	2.25	2.64	1.66	-7.73***	3.65
(SI*W)^0.5	-139.90***	59.82	-8.45	31.71	-0.78	30.31
(SI*Q)^0.5	4257.30**	2225.20	930.43	721.54	10401.00***	4285.10
(CL*W)^0.5	28.01	48.07	-8.49	23.47	-82.31***	30.67
(CL*Q)^0.5	362.70	2183.70	-149.51	624.81	-4261.60	4209.10
b_0	1.77E-04	1.90E-04	6.20E-08	2.56E-05	7.55E-05**	4.10E-05
b_1	1.07E-07	3.11E-06	3.89E-08	4.57E-07	-5.25E-07	5.68E-07
a	-121.23***	34.00	-3626.80***	1181.00	-16.71***	5.25
γ_{ncs}	-1.00***	1.67E-03	-1.06***	1.75E-02	-0.99***	9.03E-03
γ_e	-0.74***	3.60E-02	-0.99***	5.37E-03	-0.91***	9.56E-02
γ_a	-0.92***	2.81E-02	-1.00***	1.16E-03	-0.70***	6.10E-02

Previous Literature - Theory

- Limited excludability causes inefficient over-extraction.
  - Kelso (1961), Gisser and Mercado (1972, 1973), and Cummings and McFarland (1973)
- Empirically however…inefficiency quantitatively insignificant.
  - **Gisser and Sanchez (1980)**
- Assumptions in Gisser and Sanchez may not hold:
  - "Bathtub" model (confined vs. unconfined)
  - No strategic interaction among irrigators
  - Time-independent demand.
  - Nonlinearities in demand and pumping-water table relationship

Background

- Excludability is diminished by common access to an aquifer:
    - Stock externality
    - Strategic externality

- Weak excludability causes (theoretically) over-extraction of groundwater.
    - It reduces MPC of pumping relative to MSC

Comparative Statics – evenly split cost-share

- Strategic externality worsen by increased *N*
- Distortion caused by evenly split cost-sharing worsen by increased *N* for average farmer
- Reinforcing interaction between both sources of externalities for average farmer (Prop 4)
- Reinforcement stronger for large farms

Comparative Statics – area based cost-share

- Strategic externality worsen by increased N
- Distortion caused by area based cost-sharing worsen by increased N for relatively small farmers
- Reinforcing interaction between both sources of externalities for small farmers (Prop 5)
- Under proportionality both sources of externalities have offsetting rather than reinforcing effects

Comparative Statics – evenly split cost-share

- Strategic externality worsen by increased responsiveness of water table, *b*

- Under same conjectures, an increase in responsiveness of water table strengthens distortive effects of evenly split cost-share (prop 6).

- Under same conjectures, an increase in responsiveness of water table strengthens distortive effects of area based cost-share for those farmers whose share of land is lower than $\frac{1}{(1+(N-1)\gamma)}$ (prop 7).

- Reinforcement effect of externalities

Model of Water Demand

- Marginal cost of water:
  - No electricity cost-share

$$MC_{ncs} = p_k^{kwh}\left[\overbrace{\left(a + bW_k + bw_k^i\right)}^{marginal\ outlay} + \overbrace{\boldsymbol{b(N-1)\gamma_{ncs}w_k^i}}^{\boldsymbol{strategic\ externality}}\right]$$

  - Electricity cost-share

$$MC_{cs} = p_k^{kwh}\left[\overbrace{(a + 2bW_k)s_{ik}}^{marginal\ outlay} + \overbrace{\boldsymbol{(a + 2bW_k)(N-1)\gamma_{cs}s_{ik}}}^{\boldsymbol{strategic\ externality}}\right]$$

  - Marginal outlay with cost-share always lower for average farmer

Results

- Weakening of Bertrand conjectures increases marginal cost of pumping
- But cost-share rules diminishes marginal outlay
- Relative strength of forces and pumping rate:
    - Hypothesis 1 – fail to reject w/ whole sample and field crops - reject (fv); Prob > chi2 = 0.5
    - Hypothesis 2 – fail to reject w/ whole sample and field crops - reject (fv); Prob > chi2 = 0.2

- Under whole sample and field crops $A_{ncs} > A_a > A_e$

- Under fruits and vegetables sub-sample$A_a > A_e = A_{ncs}$

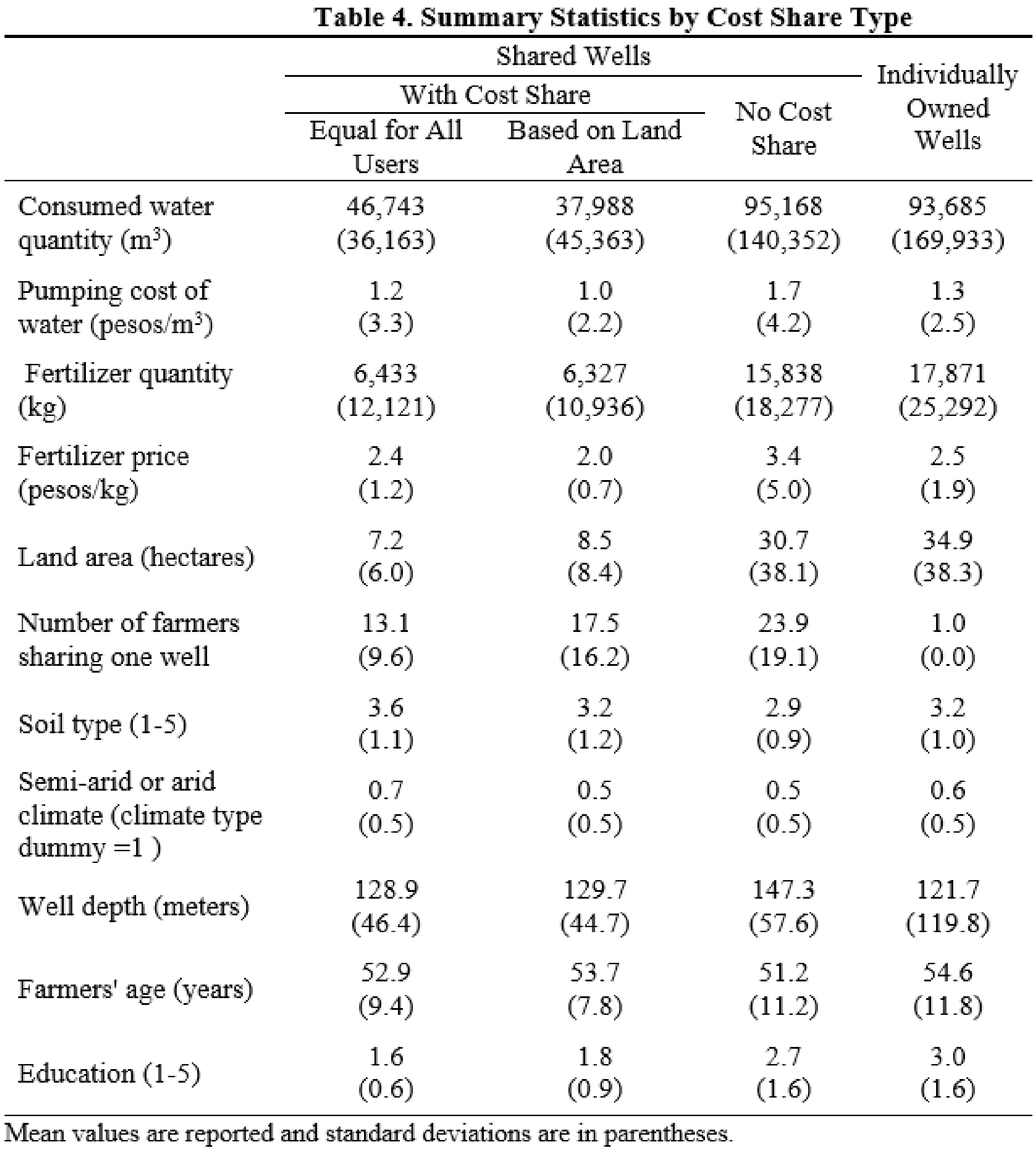


Table 4. Summary Statistics by Cost Share Type

	Shared Wells			Individually Owned Wells
	With Cost Share		No Cost Share	
	Equal for All Users	Based on Land Area		
Consumed water quantity (m^3)	46,743 (36,163)	37,988 (45,363)	95,168 (140,352)	93,685 (169,933)
Pumping cost of water (pesos/m^3)	1.2 (3.3)	1.0 (2.2)	1.7 (4.2)	1.3 (2.5)
Fertilizer quantity (kg)	6,433 (12,121)	6,327 (10,936)	15,838 (18,277)	17,871 (25,292)
Fertilizer price (pesos/kg)	2.4 (1.2)	2.0 (0.7)	3.4 (5.0)	2.5 (1.9)
Land area (hectares)	7.2 (6.0)	8.5 (8.4)	30.7 (38.1)	34.9 (38.3)
Number of farmers sharing one well	13.1 (9.6)	17.5 (16.2)	23.9 (19.1)	1.0 (0.0)
Soil type (1-5)	3.6 (1.1)	3.2 (1.2)	2.9 (0.9)	3.2 (1.0)
Semi-arid or arid climate (climate type dummy =1)	0.7 (0.5)	0.5 (0.5)	0.5 (0.5)	0.6 (0.5)
Well depth (meters)	128.9 (46.4)	129.7 (44.7)	147.3 (57.6)	121.7 (119.8)
Farmers' age (years)	52.9 (9.4)	53.7 (7.8)	51.2 (11.2)	54.6 (11.8)
Education (1-5)	1.6 (0.6)	1.8 (0.9)	2.7 (1.6)	3.0 (1.6)

Mean values are reported and standard deviations are in parentheses.

Lack of correlation between
cost of pumping and cost-share mechanism
suggests little reason to
worry about endogeneity
of the cost-share variable.