

The Roles of Cost-sharing and Common Pool Problems in Irrigation Inefficiency: a case study in groundwater pumping in Mexico

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Motivation

- Groundwater over-extraction and depletion are serious problems in many countries.
- Externalities and inefficiencies of groundwater use are important drivers of over-extraction. (Brozović, Sunding, and Zilberman 2010; Pfeiffer and Lin 2012; Huang et al. 2013)
- An understanding and quantification of different sources of externalities and inefficiencies in groundwater extraction is critical for policy design.

Motivation

- Mexico: overexploitation results in water shortages in many regions.

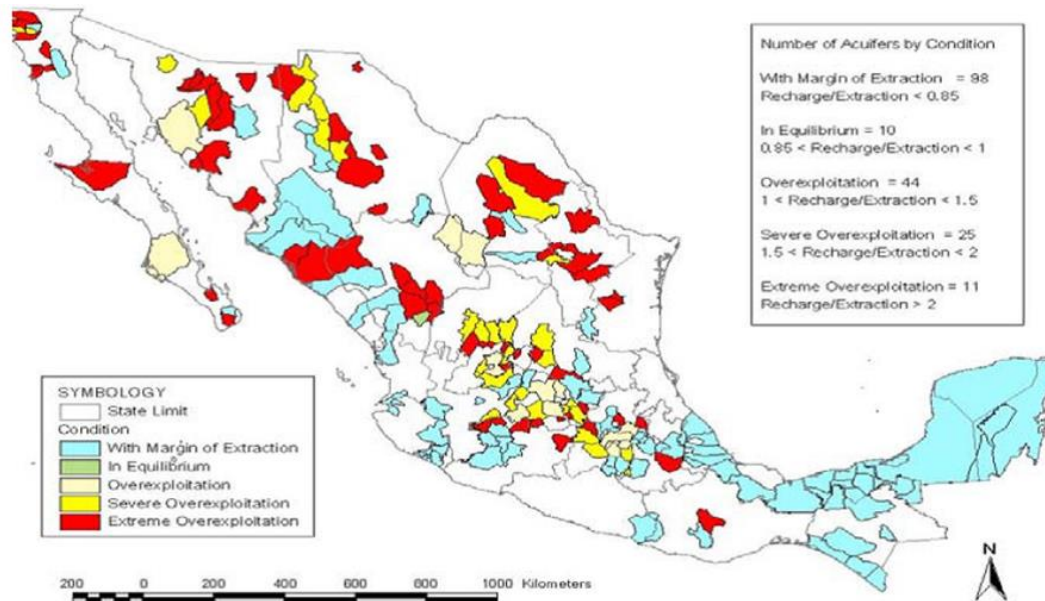


Figure 1. Aquifer depletion in Mexico

Motivation

- Federal government subsidizes the electricity used in pumping groundwater.
 - \$700 million dollars per year. (Guevara-Sanginés, 2006)
- Some wells are commonly shared by multiple farmers.
 - aggravating stock and strategy externalities.
- In some shared wells, the total cost of electricity is shared by all irrigators.
 - Cost-share externality: further distortion to marginal cost of pumping.
 - two ways to divide electricity bill
 - ✧ dividing the electricity bill evenly.
 - ✧ dividing the electricity bill based on their land share.

Objectives & Hypotheses

- **Hypothesis 1:** an increase in the cost of pumping groundwater (eliminating electricity subsidy) will not achieve a substantial reduction in irrigation.
- **Hypothesis 2:** well sharing will strengthen strategic pumping and result in greater inefficiency in irrigation application.
- **Hypothesis 3:** farmers with pre-specified electricity payment rule will be affected by the cost share externality and apply irrigation less efficiently than those paying for their own electricity consumption.

Literature

- Irrigation Demand – no inefficiency
 - Ogg & Gollehon (1989), Kanazawa (1992), Bontemps & Couture (2002), Schoengold et al. (2006), Wheeler et al. (2008), Huang et al. (2010), Sadeghi et al. (2010), Hendricks & Peterson (2012)
- Irrigation Efficiency – Stochastic production frontier; i.e. no demand
 - McGuckin et al. (1992) - inefficiency among corn producers in Nebraska (output-oriented)
 - Karagiannis et al. (2003) - inefficiency among out-of-season vegetable farmers in Greece (single-factor input-oriented)
 - Dhehibi et al. (2007) – inefficiency in Tunisia (same as Karagiannis et al.)

Model

- Input-specific efficiency (Kumbhakar 1989, Sauer and Frohberg 2007)
- Symmetric Generalized McFadden cost function

$$C^*(.) = g(p)y + \sum_i b_i p_i + \sum_i b_{ii} p_i y + \sum_i \sum_j d_{ij} p_i q_j y + \sum_j a_j \left(\sum_i \alpha_{ij} p_i \right) q_j$$

$$+ b_{yy} \left(\sum_i \beta_i p_i \right) y^2 + \sum_k \sum_j \delta_{kj} \left(\sum_i \gamma_{ijk} p_i \right) q_k q_j y,$$
(1)

$$g(p) = \frac{p' S p}{2\theta' p} \quad i = 1, 2, \dots, n, \quad k, j = 1, 2, \dots, m$$

S: n x n symmetric negative semi-definite matrix such that $s'p^*=0$

θ : a vector of nonnegative constants not all 0

P: input prices

y: output

q: fixed input

Model

- Shepherd's Lemma

$$\frac{dC(\cdot)}{dp_i} = x_i^* = \left(\frac{\sum_j s_{ij} p_j}{\sum_r \theta_r p_r} + \frac{\theta_i}{2} \left[\frac{\sum_i \sum_j s_{ij} p_i p_j}{(\sum_r \theta_r p_r)^2} \right] \right) y + b_i + b_{ii} y + \sum_k d_{ik} q_k y + \sum_k \alpha_{ik} q_k + \beta_i y^2 + \sum_l \sum_k \gamma_{ilk} q_k q_l y \quad (2)$$

$$j, r = 1, 2, \dots, n \quad k, l = 1, 2, \dots, m$$

- Adding systematic inefficiency components

$$x_i = x_i^* + \zeta_{i1} Z_{i1} + \zeta_{i2} Z_{i2} + \dots + \zeta_{iH} Z_{iH} + \varphi_i W_i + v_i \quad (3)$$

Z_{ih} : vector of variables (Z_{ih1}, \dots, Z_{ihG})

Z_{ihg} ($g = 1, \dots, G$) : observations belong to group g with respect to characteristic h which may influence the efficiency of input i

W_i : vector of control variables (climate, soil type, depth of well, farmers' age and education)

Model

- Inefficiency of input i for group g with respect to characteristic h

$$\tau_{ihg} = \zeta_{ihg} - \min_h \zeta_{ihg} \quad (4)$$

- Allocative efficiency

$$AE_{ihg} = 1 - \tau_{ihg}/x_{ihg} \quad (5)$$

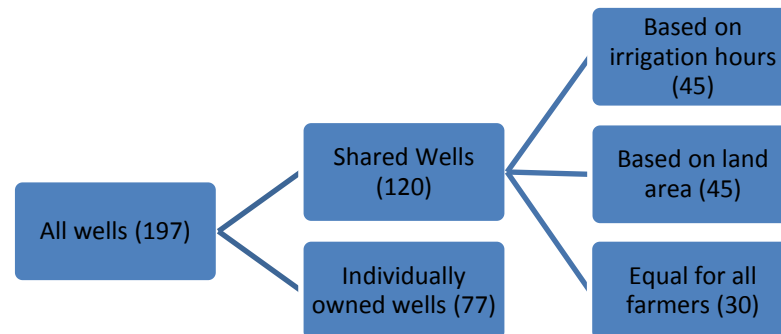
- Cost increase from inefficiency

$$CAE_{ihg} = p_{ihg}\tau_{ihg}/C_{ihg} \quad (6)$$

Data

- Survey conducted in Mexico by the National Institute of Ecology (INE) from 2003 to 2004
- Variables
 - Variable inputs: water, fertilizer and other inputs
 - Fixed input: land
 - Aggregate output: field crops, fruits, vegetables

- Wells



Estimation

- Three inputs demand equations
- Non-linear Seemingly Unrelated Regression
- Including well sharing dummy

$$x_i = x_i^* + a_1 * Singly + a_3 * Landshare + a_4 * Evenly + a_5 * SI + a_6 * CL + a_7 * DEPTH + a_8 * AGE + a_9 * EDUCATION + v_i. \quad (7)$$

Results

- Coefficient for water demand with well sharing dummy

<i>Water equation</i>	<i>Estimation</i>
Constant	-28716.3(32662.6)
Output quantity	461.6* (240.5)
Interaction of land area and output quantity	-97.3*** (35.4)
Land area	3185.6*** (391.3)
Quadratic term of output quantity	2.4*** (0.9)
Interaction of quadratic land area and output qua	1.0** (0.5)
Dividing electricity bill by share of land area	13914.6 (11641.7)
Dividing electricity bill evenly	23693.2* (12740.5)
Singly-owned wells	-6094.0 (15433.3)
Soil type	6358.5 (5863.6)
Climate type	10698.4 (12661.5)
Depth of well	45.2 (53.6)
Age	-215.4 (429.7)
Education	3856.8 (4601.2)
Own price elasticity of water	-0.06** (0.02)

Estimation

- Including number of farmers sharing wells

$$x_i = x_i^* + c_1 * Landshare + c_2 * Evenly + c_3 * N + c_4 * SI + c_5 * CL \\ + c_6 * DEPTH + c_7 * AGE + c_8 * EDUCATION + v_i. \quad (8)$$

- Farmers' reaction to cost share are affected by the number of farmers sharing wells or electricity bill. (See model in paper.) The estimation of cost sharing effect with controlling the number of farmers is more reliable.

Results

- Coefficient for water demand in 3 groups estimation

<i>Water equation</i>	<i>Estimation</i>
Constant	-39040.3(32579.8)
Output quantity	486.1** (244.6)
Interaction of land area and output quantity	-97.3*** (34.7)
Land area	3178.8*** (390.2)
Quadratic term of output quantity	2.4*** (0.9)
Interaction of quadratic land area and output quantity	1.0** (0.5)
Dividing electricity bill by share of land area	16158.7** (8107.7)
Dividing electricity bill evenly	26440.9*** (8567.3)
Number of farmers sharing a well	265.5 (314.0)
Soil type	6742.4 (5839.7)
Climate type	13367.5 (13268.8)
Depth of well	42.5 (52.1)
Age	-214.9 (425.8)
Education	4306.6 (4615.4)
Own price elasticity of water	-0.06** (0.02)

Results

- Own-price elasticity of groundwater is -0.06.
 - Price-based policies (eliminating electricity subsidy) are only effective if a significant increase in pumping cost is implemented.
- Both well sharing and the number of farmers sharing a well has no significant impact on water application.
 - Well sharing does not aggravate stock and strategy externalities.

Results

- Efficiency level and cost increase due to inefficiency

Farmers	Allocative Efficiency	Cost Increase
Farmers paying their own actual electricity consumption	1.00	0%
Farmers dividing electricity bill based on their land share	0.57	22%
Farmers dividing electricity bill evenly	0.43	31%

- Implementing metering systems that allows charging each farmer for his own electricity consumption is effective to reducing water pumping.
- Removal of cost-sharing will not only alleviate groundwater depletion but also improve farmers' welfare.

Conclusions

- Price-based policies (e.g. elimination of electricity subsidies) may not be very effective instruments to achieve a substantial reduction in pumping.
- Policies aimed at reforming well sharing only, not common pool problem of groundwater, cannot have significant effect on groundwater pumping.
- Policies aimed at reforming cost-sharing would be more effective in alleviating groundwater depletion.

Thank you!

Questions and comments are welcome.