Water-efficient irrigation technology adoption in Punjab

Molly Van Dop[1], Homan Sheng[2], Juan Sesmero[3], and Taisha Venort[4]

[1] MS student, Department of Agricultural Economics, Purdue University, IN 47907-2056, USA,

mvandop@purdue.edu

[2] MS student, Department of Agricultural Economics, Purdue University, IN 47907-2056, USA,

qiang@purdue.edu

[3] Assistant Professor, Department of Agricultural Economics, Purdue University, IN 47907-2056, USA,

jsesmero@purdue.edu

[4] MS student, Agricultural and Biological Engineering/Ecological Sciences and Engineering, Purdue University, IN 47907-2114, USA, tvenort@purdue.edu

Selected Poster prepared for presentation at the 2015 Agricultural & Applied Economics Association and Western Agricultural Economics Association Joint Annual Meeting, San Francisco, CA, July 26-28

Summary
We examine key features of the adoption of water-efficient irrigation technologies in the Punjab region in India. Results show that the government would have to incur significant costs to induce adoption of irrigation technologies. Moreover, adoption of efficient technologies may not deliver reductions in water pumping due to the "rebound effect". In combination these results suggest a low cost-effectiveness of policies supporting efficient irrigation systems.

Background and Contribution

Water scarcity is an issue that has quickly taken the spotlight as a primary challenge of modern agriculture. Although this issue has worldwide effects, the biggest impacts have been made in countries where the water markets have the least structure, and poorly reflect the social costs of using water. A key area that reflects this growing conflict is in the arid regions of India. A combination of the Green Revolution encouraging water-intensive crops in low-income regions, government subsidies for irrigation infrastructure, and lack of consistent rainfall makes this region a hotspot for conflict. Punjab, in particular, has been using groundwater at over 100% of its recharge rate, and has little surface water available (Rodell 2008). Satellite images of Punjab show that soil water levels remain constant while groundwater levels reach all-time lows, suggesting that the water depletion problem is human-induced.

A variety of water-efficient irrigation technologies is available for farmers in Punjab. Adoption of such technologies may help alleviate pressure on groundwater and enhance the long term sustainability of food production in this region. Yet there is a dearth of information on the economic viability of such technologies and potential barriers to their adoption. The goal of this paper is to examine the economic viability of water-saving technologies available to rice farmers in Punjab. In particular, our objective is to quantify farmers' willingness to accept for water-conserving technologies and, consequently, the subsidy (if any) needed to induce their adoption.

While widespread adoption of water-efficient irrigation systems may favor water conservation, it can also yield unintended consequences. More efficient technologies reduce the marginal cost of pumping (due to increased water table levels and water pumped per unit of cost) encouraging, all else constant, more irrigation. Additionally, it slows down or even prevents conversion of land to less water-intensive crops. These forces, which distinctly occur at the intensive and extensive margins respectively, increase pumping, at least partially offsetting the water-saving nature of the efficient technologies. The literature has labelled this the "rebound effect". Therefore the overall impact of adoption of water-efficient technologies on groundwater is, ultimately, an empirical question. We examine these issues by quantifying the optimal rate of groundwater pumping under alternative technologies and crops.

We model a representative, profit-maximizing farmer who solves a sequential optimization problem. First, the farmer decides what crop to grow. Second, the farmer decides on the irrigation technology used to grow that crop. Finally, the farmer decides how much water to apply during the growing season (under average weather conditions) to the selected crop with the chosen technology. The optimization problem is solved by backward induction. Water for irrigation is extracted from aquifers that are, by their hydrological nature, common access to multiple farmers. The strength of the externality associated with the common access nature of the aquifer will influence the profit-maximizing irrigation application in the field (Betigeri 2014). In turn, the strength of the externality depends on the degree of storativity and connectivity of wells. Therefore, modeling and quantification of irrigation demand requires explicit consideration of not only technology and crop choice, but also the response of the water table to extraction and, if any, strategic considerations underlying farmers behavior.

A dynamic optimization problem is solved under multiple “regimes”. Each regime is composed by a combination of crop and irrigation technology. The amount of irrigation water pumped under each regime determines the time evolution of groundwater in the area under analysis. In turn, water application will be determined by crop prices, the productivity of water, and production cost. These forces will also determine which regime will prevail over others. Since we are interested in the long term (i.e. steady state) situation of the aquifer, we use a static model depicting steady state equilibria under different regimes. Our model is based on breakeven conditions depicting the combination of economic and biophysical condition under which two different regimes result in similar net returns.

Choice of regime and associated irrigation water demand are derived in the context of a two-person game which, at the expense of empirical richness, allows formalization and identification of extraction drivers under alternative institutional arrangements. A Nash equilibrium is found analytically. Based on optimal policy functions at equilibrium we find combinations of biophysical and market conditions under which the representative farmer is indifferent between alternative regimes. These thresholds are then used to find dominance regions; i.e. combinations of prices and biophysical conditions under which specific regimes dominate all others. Empirical results are found by calibrating parameters and quantifying thresholds.

Yield (metric tons per hectare) functions are approximated with a quadratic function of irrigation (cubic meters per hectare). Biophysical parameters of such yield functions are calibrated based on productivity and price data from Cho and Oki (2012). The link between groundwater depth and cost of pumping was assumed linear and quantified based on data from the irrigation decision tool from the Institute of Agriculture and Natural Resources at the University of Nebraska, Lincoln. NASA satellites were used in conjunction with a hydrological modelling system in Punjab, Rajastan, and Haryana to determine that groundwater is being depleted at a mean rate of 4.0 ± 1 cm/yr, due to an extraction of 17.7 cubic kilometers of water a year (Rodell, 2008). This information was used to calibrate the groundwater depth function.

Preliminary results suggest that positive and significant subsidies are required to induce farmers to adopt water efficient technologies. Moreover, results also suggest that, under plausible parametric conditions, the “rebound effect” prevails and that water efficient technologies may in fact result in greater extraction. The rebound effect can be decomposed into two effects; one taking place at the intensive margin and one at the extensive margin. The former consists of increases in irrigation application across regimes. The second is driven by the fact that water-intensive regimes become more likely to be adopted; i.e. the size of the region in which water-intensive regimes dominate all others increases. These insights cast light on both the viability and reliability of policies supporting water-efficient irrigation systems in Punjab.

Finally, results also show that, while irrigation application rates seem to be strategic substitutes among farmers sharing an aquifer (as found in previous literature), decisions on adoption of water-efficient technologies are strategic complements. The latter is a novel result as the strategic nature of technology adoption has received little attention in the extant literature.

References

Rodell, Matthew, Isabella Velicogna, and James S. Famiglietti. "Satellite-based Estimates of Groundwater Depletion in India." Nature 460.7258 (2009): 999-1002. Web.

Betigeri, Arti. "How India's Subsidized Farms Have Created a Water Crisis." Public Radio International. N.p., 03 July 1014. Web.

Oki and Cho. “Application of Temperature, Water Stress, CO_2 in rice growth models” The rice journal, 2012.