Long-Term Tradeoffs between Private and Social Objectives in the High Plains Aquifer

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Summary

This study examines the long-term tradeoffs between private economic land rents and social objectives related to the environment and agricultural output in the High Plains aquifer region of the U.S. It does so by developing an empirical dynamic optimization model characterizing steady state solutions for rent maximization under alternative policy-imposed constraints on the social objectives. We quantify the extent to which neutral and biased technical progress affect the tradeoffs among these objectives. We also examine the effect of climate change on these tradeoffs. A key finding illustrates how a high production target (i.e. producing enough biomass to match expected demand growth, instead of maximizing profits) will put particular pressure on water resources – more so than on crop extensification and fertilizer/chemical application. Our results also suggest that projected changes in climatic conditions will result in a reduction in cropping extensification, and an increase in water-intensification. This implies that: climate change will intensify groundwater depletion in this region, and thus amplify the benefits from water-saving innovations.

Background and Contribution

Aquifers are an important source of fresh water worldwide, including supplies for human food, fiber and fuel needs, environmental aesthetics, and ecosystem services. The aquifers of the world currently contribute substantially to agricultural production. Groundwater for irrigation accounts for nearly 40% of world-wide freshwater withdrawals for consumptive use (Siebert, et al, 2010). Among the aquifers in the U.S., the High Plains Aquifer (HPA) accounts for the most irrigation withdrawals, which have resulted in depletion of up to half the water in some southern areas, and a depletion of 8% overall (Scanlon, et al, 2012).

Crop production within the HPA region accounts for 31% of US sorghum production, 24% of cotton, 15% of wheat, and 14% of corn. Thus the aquifer represents a significant fraction of this country's ability to meet its share of the increasing world demand for agricultural products. Sustainable long-term aquifer management is thus critical for future social welfare and ecosystem health. Yet, because aquifers are essentially common-pool resources, sustainable management is often challenging in light of increasing pressures for exploitation and a general lack of long-term strategies to guide sustainable management. Our overarching goal is ***to quantify the potential long-run tradeoffs among private and social objectives in the High Plains Aquifer (HPA).*** The private objective is maximum long-run land rents subject to groundwater constraints. The long run social objectives considered are (1) agricultural biomass output for food, feed, fiber and fuel; (2) limits to groundwater depth, (3) limits to crop extensification, and (4) limits to fertilizer and chemical use.

Methods

Our unit of observation is county-year. We model agricultural production through a Cobb Douglas function linking 4 inputs to aggregate agricultural biomass output. The four inputs are: share of total land in the county allocated to crops (cropping extensification), total fertilizer applied in the county, total amount of other chemicals (damage control inputs such as herbicide and insecticide) applied, and the share of land under irrigation in the county (water intensification). A county-level panel data set is used to estimate, by three stage least squares, the biomass production function.

An increase in the share of land under irrigation is associated with increased groundwater extraction and a reduction in the water table in future periods. Such increase in groundwater depth translates into increased extraction cost and reduced future profits. This intertemporal effect introduces a dynamic component to the management problem. Using county-level panel data, we estimate an equation of motion quantifying the link between the share of land under irrigation and the change in groundwater depth. We use previously published estimates of the effect of increased groundwater depth on extraction cost.

We frame the private land rent management problem as one in which the trajectory of control variables (the four production inputs) is chosen to maximize profits subject to the biomass production function, the aquifer depth equation of motion, and alternative resource extraction constraints. We calculate the steady state solution values to this problem, and contrast it with five alternative scenarios: a scenario in which extensification (share of land under crops) is reduced by 10%, a scenario in which water intensification (share of agricultural land under irrigation) is reduced by 10%, a scenario in which fertilizer intensification is reduced by 10%, a scenario in which chemical intensification (application of herbicide and insecticide) is reduced by 10%, and a scenario in which biomass production is forced to increase 2% per year. All prices are exogenous. Comparisons between scenarios reveal the tradeoffs between competing objectives.

We subsequently examine the effect of climate change and technical progress on tradeoffs. Predictions of climatic conditions for the period 2030-2069 are drawn from the Coupled Model Intercomparison Project (CMIP5), assembled by the World Climate Change Research Program. Neutral technical progress is captured by a total factor productivity index included in the estimated Cobb Douglas biomass production function. Biased technical progress is captured by increases in coefficients that determine the elasticity of production with respect to each input.

Conclusions and Policy Implications

Preliminary results show how, as the biomass production target increases, a higher share of land is irrigated which translates into a substantial increase in groundwater depth. Although increases in other inputs are also observed, they are lower in magnitude. Our results show how limits to fertilizer and chemical intensification also result in increased depletion of groundwater. Limits to irrigation, on the other hand, translate into large reductions in output and economic rents.

Our preliminary analysis also shows that water-saving innovations are particularly effective at reducing the social objectives given up per unit of output or land rent. This suggests that water-saving technological progress may yield broader societal benefits than other types of innovation. Neutral technical progress is particularly effective at relaxing tradeoffs between production and economic targets. But it does not seem as effective in reducing environmental objectives given up per unit of production or land rent.

Finally, projected changes in climatic conditions will put more pressure on water resources. In combination with water conservation policies (embodied by constraints on share of land under irrigation) they result in a large reduction in biomass production and economic rents. Therefore the value of water-saving innovations will greatly increase, as climate change unfolds.

References

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