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Does efficient irrigation technology lead to reduced groundwater extraction? Empirical evidence

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ABSTRACT

Encouraging the use of more efficient irrigation technology is often viewed as an effective, politically feasible method to reduce the consumptive use of water for agricultural production. Despite its pervasive recommendation, it is not clear that increasing irrigation efficiency will lead to water conservation in practice. In this paper, we evaluate the effect of a widespread conversion from traditional center pivot irrigation systems to higher efficiency dropped-nozzle center pivot systems that has occurred in western Kansas. State and national cost-share programs subsidized the conversion. On an average, the intended reduction in groundwater use did not occur; the shift to more efficient irrigation technology has increased groundwater extraction, in part due to shifting crop patterns.

> It is a confusion of ideas to suppose that the economical use of fuel is equivalent to diminished consumption. The very contrary is the truth.
>
> -William Stanley Jevons, “The Coal Question” (1865)

Agriculture accounts for 99% of groundwater withdrawals from the High Plains Aquifer of the central United States, the largest freshwater aquifer system in the world (Miller and Appel, 1997). The region has experienced a decline in the level of the groundwater table since the 1970s, when intensive irrigation became widespread and led to rates of extraction that far exceeded recharge to the aquifer. In parts of southwestern Kansas and in the Texas panhandle, the depth to groundwater has increased by more than 150 ft. Many of the world′s most productive agricultural basins depend on groundwater and have experienced similar declines in water table levels. Increasing competition for water from cities and environmental needs, as well as concerns about future climate variability and more frequent droughts, has caused policy makers to declare “water crises” and look for ways to decrease the consumptive use of water. Agriculture, by far the largest user of water, is often targeted.

Irrigated agriculture is often believed to be wasteful. In response, policy makers have called for measures that increase the efficiency of irrigated agriculture. In fact, large sums have been spent on programs to increase irrigation efficiency in agriculture, many of them are incentive-based cost-share programs that subsidize the conversion to more efficient irrigation technology. These programs have the advantage of being extremely popular and therefore politically feasible. Numerous state and national governments, international organizations, and scientists have called for additional programs to support conversion to more efficient irrigation technology (Cooley et al., 2009; Jury and Vaux, 2005; Zinn and Canada, 2007; Johnson et al., 2001; Evans and Sadler, 2008). However, there have been very few evaluations of these programs, and of those that exist, many raise serious doubts about the programs′ effectiveness in reducing the consumptive use of water. A debate has

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emerged between those positing that irrigation efficiency enhancement can make significant amounts of water available for other uses (Cooley et al., 2009) and those that point out that these policies may have unintended consequences such as increasing total irrigated acreage, increasing evapotranspiration and yields of existing crops, a shift to more water intensive crops, and a reallocation of within-basin water supplies, potentially increasing overall consumptive use (Ward and Pulido-Velazquez, 2008; Whittlesey and Huffaker, 1995; Ellis et al., 1985).

In this paper, we empirically investigate the effect of a wide-spread conversion to efficient irrigation technology on groundwater extraction in Kansas, a state that overlies the High Plains Aquifer. Recently, several studies have shown that shifting to more efficient irrigation technology does not necessarily reduce total water use, and can even lead to increases in water use (Ward and Pulido-Velazquez, 2008; Scheierling et al., 2006; Peterson and Ding, 2005; Huffaker and Whittlesey, 2003; Khanna et al., 2002; Hanak et al., 2010). These studies used deterministic programming models or simulation approaches. In contrast, we econometrically evaluate changes in irrigation behavior after conversion from conventional center pivot irrigation systems to a more efficient technology: center pivots with dropped, high efficiency nozzles. We use panel data from over 20,000 groundwater-irrigated fields in western Kansas from 1996 to 2005. We find that as the shift to more efficient dropped nozzle irrigation technology occurred, the amount of groundwater applied to fields in Kansas increased. This was due to increases in water use on both the intensive and extensive margins. On the intensive margin, farmers used more water per acre on irrigated fields. On the extensive margin, farmers irrigated a slightly larger proportion of their fields and were less likely to leave fields fallow or plant non-irrigated crops.

Background

Irrigation efficiency is defined as the proportion of consumed water (also called “consumptive use”) that is beneficially used by a crop (effective water) (Burt et al., 1997):

$$\text{Irrigation efficiency} = \frac{\text{Effective water}}{\text{Consumptive use of water}}. \tag{1}$$

More efficient irrigation systems increase this proportion, allowing less water to be applied for a given yield. In many watersheds, some portion of the irrigation water applied is available for other uses downstream via runoff, or recharges the aquifer via percolation. In these cases, the “consumptive use of water” is equal to applied water minus this return flow, and the spatial unit of irrigation efficiency must be defined because irrigation efficiency at the basin level would diverge from that at the field level by the amount of water that is reused (Huffaker, 2008; Ward and Pulido-Velazquez, 2008; Huffaker and Whittlesey, 2000). In the portion of the High Plains Aquifer underlying western Kansas, however, recharge to the aquifer by irrigation water that runs off, percolates, or is otherwise not used by the crop but is available for future use is negligible (Miller and Appel, 1997). Thus, we can define the consumptive use of irrigation water equal to the amount of water extracted from the aquifer and applied to the field, and define irrigation efficiency as Eq. (1), at the field level (Peterson and Ding, 2005).

The irrigation technology employed by groundwater users in western Kansas has changed significantly since intensive irrigation development began with flood systems in the 1970s. Through the 1980s, land was converted from flood irrigation, which is labor and water intensive and necessitates flat, high quality, uniform land, to center pivot irrigation systems. Center pivots are generally self-propelled and can be used on sloped or rolling land, but require a higher pressure at the pump to operate (Rogers et al., 2008). Fig. 1 shows the trend in irrigation technology use in western Kansas from 1996 to 2005, the time period used for our analysis. Center pivot systems were already widespread by 1996. Rather, most of the changes came in the conversion from center pivots to center pivots with dropped nozzle packages. Dropped nozzle packages (also called low-pressure nozzles or low energy precision application (LEPA)) are attached to center pivots and suspend the sprinkler heads between about 2 ft above the ground to just above the canopy of the crop. They increase the efficiency of water

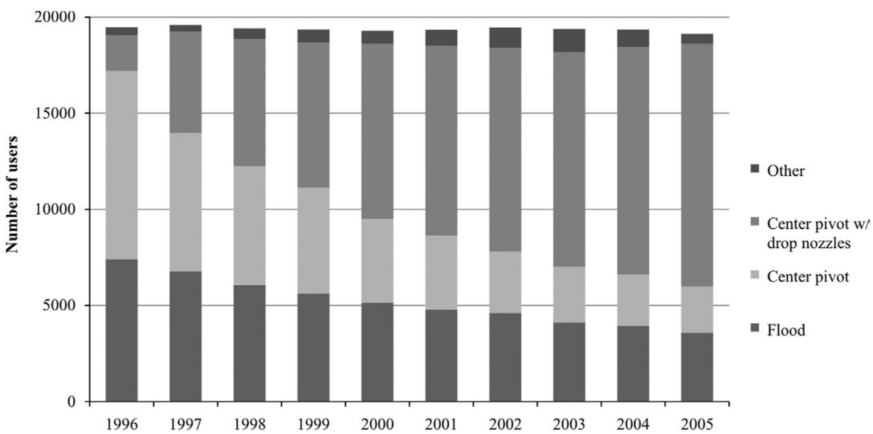

Fig. 1. Irrigation technology used in western Kansas by groundwater users, 1996–2005. Source: WIMAS data.