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Laser-land leveling adoption and its impact on water use, crop yields and household income: Empirical evidence from the rice-wheat system of Pakistan Punjab

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ABSTRACT

Using a primary dataset from 350 farmers from the rice-wheat area of Pakistan Punjab, we estimate the impact of laser-land leveling on water saving, crop yields and household income. The analysis employs propensity score matching (PSM) to correct for the potential sample selection bias that may arise due to systematic differences between adopting and non-adopting farmers. In the study, 57% of farmers had access to laser land leveling, with an important role for service providers. Adoption of laser-land leveling has a positive impact on irrigation water savings, wheat and rice yields and household income. The study suggests policy implications for making laser land leveling access and performance more socially inclusive through enhanced awareness, institutional support to service providers and public-private partnerships.

1. Introduction

Modern farming technologies are a driver for agricultural growth and development. The use of such technology can increase crop yields and household incomes, enhance rural livelihoods and reduce pressure on natural resources (Mendola, 2008; Smith, 1998). But the adoption of agricultural technologies differs across countries and is variously affected by natural resources, cultural, political, and socioeconomic conditions (Nkonya et al., 1997). Agricultural technology adoption has been variously studied in several countries (Doss, 2006; Feder et al., 1985; Lee, 2005; Mercer and Pattanayak, 2003; Pattanayak et al., 2003), including developed countries (Rahm and Huffman, 1984; Smit and Smithers, 1992; Weersink et al., 1992) and developing countries (Aryal et al., 2015b; Asfaw et al., 2012; Kassie et al., 2013, 2011; Lee, 2005).

Agricultural intensification through the adoption of improved seed, fertilizer and irrigation was central to the Green Revolution that transformed South Asia's rural landscape and food security in the late 20th century. This gave rise to the intensive irrigated rice-wheat systems that span much of South Asia's Indo-Gangetic Plains (IGP) (Timsina and Connor, 2001). But off-late, South Asia's agricultural production is challenged by climate change and depleting water resources (Hijioka et al., 2014) and the region's irrigated systems are no exception (Erenstein, 2009). Water availability indeed plays a critical role in agricultural production and food security (Brown and Funk, 2008). This has lead to a quest for improved agricultural water management and the associated use of water conserving technologies (Ambast et al., 2006; Hanjra and Qureshi, 2010).

Rice-wheat systems typically rely on surface irrigation, primarily sourced from groundwater through irrigation tube wells (Erenstein, 2009). Slight field irregularities/unevenness thereby significantly affect irrigation water use efficiency, resulting in 10–25% losses of irrigation water in the rice-wheat system of the IGP (Kahlown et al., 2000). Farmers have long used traditional land leveling techniques through tillage to level and even out fields during land preparation. Laser land leveling (LLL) provides a more precise and rigorous land leveling using a laser-equipped drag bucket. LLL can markedly reduce irrigation water use and save energy through the reduced duration of irrigation (Jat et al., 2009, 2011). Uniform fields enhance irrigation efficiency through a better water distribution and diminish nutrient loss through enhanced runoff control, resulting in higher efficiency of fertilizer use and higher yields (Jat et al., 2009, 2011). LLL can also increase yields through better crop germination and crop stands (Jonish, 1991; Mallappa and Radder, 2012; Ren et al., 2003; Rickman, 2002).

The literature generally highlights positive impacts of LLL on irrigation water use and farm productivity. In the Indian north-western

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IGP, adoption of LLL on paddy fields reduced irrigation by 47–69 h/ha/season and raised yield by almost 7% compared to conventionally-leveled fields, and on wheat fields, the irrigation time declined by 10–12 h/ha/season and yields improved by 7–9% (Aryal et al., 2015a). LLL adopting farmers thereby benefited by an additional US$143.5/ha/year through increased yields and reduced electricity use (Aryal et al., 2015a). LLL benefits have also been reported elsewhere, for instance, the average annual net income and gross margin from cotton farming in LLL fields in Tajikistan was 22% and 92% higher than from control fields (Abdullaev et al., 2007). However, some studies have reported mixed impacts or flagged certain aspects, e.g., Subramanian and Martin (2011); Parfitt et al. (2014); Jat et al. (2009); Abdullaev et al. (2007).

The objective of the present study is to assess the adoption of laser-land leveling in the rice-wheat systems of Pakistan Punjab and specifically its impact on water use, household income and crop yields. The contribution of the study thereby is twofold. First, there is limited documented evidence from LLL adoption and impacts in Pakistan (especially compared to India) whereas much of the pioneering LLL work in rice-wheat systems was done there. Second, there is a need to control for potential selection bias in LLL adoption and impact studies. Few studies have focused on the impact of LLL in Pakistan, but none has considered potential sample selection biases. In the current paper, the propensity score matching is employed to correct for potential sample selection bias. A brief description of the LLL technology in Pakistan is presented in the next section, followed by the conceptual framework and methods in Section 3. The data and description of variables is summarized in Section 4. In Section 5, findings from the econometric models are presented. The paper closes in Section 6 with some policy recommendations.

2. Laser land-leveling technology in Pakistan

In Pakistan, agriculture remains a major economic sector: it contributes 21.4% to GDP, provides employment to about 45% of the country's working population and supports the growth of other sectors of the economy (Government of Pakistan, 2013). The noteworthy crops cultivated in Pakistan include cash crops (cotton and sugarcane) and food crops (wheat, rice, maize, fruit and vegetables) which collectively contribute to more than 75% of the total agricultural output value (Government of Pakistan, 2005-06). Primary commodities (rice and cotton) and processed and semi-processed products (cotton yarn, cloth, carpets and leather products) constitute almost 60% of the total exports. Despite structural changes in the Pakistani economy over the last decades, agri-based products remain important and agriculture a cornerstone for development and growth (Government of Pakistan, 2003).

In 2010–11, of the total cultivated area of 21.41 million hectares in Pakistan, about 18.63 million hectares was irrigated, primarily (94%) under surface/flood irrigation. The availability of water is declining; hence, there is a need to improve irrigation efficiency and adopt water saving methods. Nearly 50% of the available irrigation water in the country is lost while being applied to the fields (Gill, 1994), with 20–25% loss due to uneven fields and poor farm design. This results in an over-application of water in low-lying areas and an under-application on higher points in the fields. Laser land leveling (LLL) is an agricultural field practice to flatten the cropland to an even level plane with a variation of less than ± 20 mm. LLL decreases the cost of operation and ensures a greater degree of accuracy in much lesser time than traditional land leveling. LLL can assist in a more uniform distribution of water (Brye et al., 2005; Walker, 1989) and thereby help save 20–30% of irrigation water and improve crop yields by 10–20%. LLL was introduced in 1970 – and potentially would elevate surface irrigation efficiency to that of sprinkler and drip irrigation (Erie and Dedrick, 1979).

In Pakistan, LLL was introduced in the irrigated systems of Punjab and has been promoted by the department of On-farm Water Management (Ahmad et al., 2001; Sattar et al., 2003). Early studies in Okara and Rahim Yar Khan districts (27 farmers) documented 25–48% savings in irrigation water, 12% improvement in the yield of cotton, wheat and sugarcane, a 2% reduction in area under unnecessary water control structures like ridges, ditches and dykes and an increase in the area under high-value crops (Government of the Punjab, 2008). LLL still is quite a new technology to many farmers and areas. LLL implies a capital investment in the needed LLL implements and a skilled worker to manage the laser settings and run the tractor. In Pakistan both imported and locally manufactured laser land leveling units are available on the market. The price of a complete laser land leveling unit is in the order of Pakistan Rs. 500–600 k and includes a laser transmitter, control box, receiver, wires and hydraulic operated scrapper. At present, there are an estimated 8500 LLL units in the Pakistan Punjab: about 5500 provided through government (subsidy) schemes and 3000 procured by farmers privately/commercially. Some 4000 units were provided since 2005, including 2500 subsidized units and 1500 unsubsidized units. Many of the LLL units are operated by service providers who provide LLL services to farmers on a rental basis throughout the province – making the technology more accessible by making the lumpy technology divisible and providing the needed operational skills, although potential economies of scale may generate bias in favor of leveling larger plots. LLL also implies a land improvement that lasts several seasons and thus favors landowners and secure land tenure. LLL does imply a field operation in the absence of a standing crop – implying relatively short implementation windows between the crop seasons in the intensively cultivated irrigated rice-wheat systems with typically two crops per year.

3. Analytical model

3.1. Technology adoption

Agricultural technology adoption decisions are influenced by a number of farm household, technology and contextual characteristics, e.g., Boahene et al. (1999); Mbaga-Semgalawe and Folmer (2000); Tang et al. (2016). Adoption studies have variously confirmed the influence of factors related to underlying farm characteristics (Clay et al., 1998; Nkonya et al., 1997; Polson and Spencer, 1991), capital and labor markets (Feder et al., 1985; Fujisaka, 1993; Neill and Lee, 2001), demographic and human capital (Sureshwaran et al., 1996) and social and institutional variables. Farm size is considered an important determinant, albeit that the adoption effect has been variously found to be positive (Abara and Singh, 1993; Feder et al., 1985; Fernandez-Cornejo, 1996; McNamara et al., 1991), negative (Harper et al., 1990; Yaron et al., 1992) or neutral (Mugisa-Mutetikka et al., 2000). In the case of LLL adoption in the irrigated rice-wheat systems, we particularly foresee the importance of institutional support (e.g., service providers, agricultural extension, credit) and farm capital (human, physical) and hypothesize that adopters have better support and assets.

It is assumed that LLL adoption is a binary decision. Farm households will take on LLL if the net returns from adoption is higher than non-adoption. The variance between the net return from LLL adoption and non-adoption is designated as E^*, such that $E^* > 0$ shows that the net earnings from LLL adoption surpass that of non-adoption. Although E^* is unobservable, it can be stated as a function of apparent variables in the following latent variable model:

$$E_i^* = \beta Z_i + \mu_i, \quad E_i = 1[E_i^* > 0] \tag{1}$$

where E_i is a binary variable which is equal to one for farm household i if they adopt LLL and 0 otherwise, β is a vector of parameters to be assessed, Z_i is a vector of household and plot-level features and μ_i is an error term presumed to be normally distributed.

The likelihood of LLL adoption by the farm household can be denoted as:

$$\Pr(E_i = 1) = \Pr(E_i^* > 0) = \Pr(\mu_i < -\beta Z_i) = 1 - F(-\beta Z_i), \tag{2}$$