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Empowering irrigation: A game-theoretic approach to electricity utilization in Indian agriculture

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ABSTRACT

This research uses a game-theoretic approach to analyze electric power provision for irrigation in Andhra Pradesh, based on results from interview and survey data. Farmers face a coordination problem of collectively preserving electric power quality and a linked dilemma of obtaining sufficient electric infrastructure capacity from utilities. Low equilibria prevail due to asymmetric payoffs and farmers not knowing electric network properties. The findings derived from survey data, empirical tests, and model synthesis indicate how the capacity dilemma can be overcome to enable coordinated technology adoption via farmers' and utilities' investment into energy-efficient and economically viable technology. Coordinated demand-side measures could effectively reduce energy use and support adaptation to climate change.

1. Introduction

Since the late 1970s, the political economy of party competition over a large agricultural electorate has created persistent subsidization politics in India (Birner et al., 2007; Kimmich, 2016; Shah et al., 2012). In many Indian states, electricity for agriculture is provided through a very low and unmetered flat-rate price system. This has spurred the diffusion of tube-well irrigation technology. In the states of Andhra Pradesh,[1] with major electricity-driven irrigation and early policy adoption, irrigation technology has spread at an average annual growth of seven percent in terms of new connections since 1980 (see Fig. 1), with more than 3.2 million pump sets connected in 2014 (CEA, 2014). As a result, the average share of total electric energy consumption attributed to agriculture has grown by 13 percent annually since 1980, peaking at 36 percent in 2007. In addition, a large share of transmission and distribution losses, standing at 19 percent of all electricity generated in 2007 (CMIE, 2008), can be ascribed to distributing electricity to agricultural connections.

Electricity use for irrigation is highly inefficient. A comprehensive pump set rectification and standard improvements can yield efficiency gains of up to 50 percent (Reidhead, 2001; Sant and Dixit, 1996), simultaneously lowering subsidy payments for the state and mitigating climate change (Mathy and Guivarch, 2010). Demand-side management on the electricity side of irrigation can provide a major contribution toward energy efficiency and contribute to sustainable development (Shah et al., 2008; Srivastava and Rehman, 2006) and climate change adaptation (Kimmich, 2013b), but an enabling regulatory practice is a prerequisite (Dubash and Rao, 2008; Ruet, 2005). Under the given electricity price regime, motor efficiency improvements are not profitable for farmers (McNeil et al., 2008).

The subsidization policy has also led to a steady deterioration of electric infrastructure quality (Shah, 2009; Tongia, 2007). Although partly compensated for supplying subsidized agricultural electricity by the state, the distribution companies have steadily reduced investments, maintenance, and staff budgets for rural distribution. This has resulted in reduced monitoring capacities and

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[1] In 2013, parts of Andhra Pradesh became independent, and a new state, Telangana, was formed. Here we use the term Andhra Pradesh to refer to the situation before 2013, i.e. both Andhra Pradesh and Telangana. The empirical data used here were collected before 2013.

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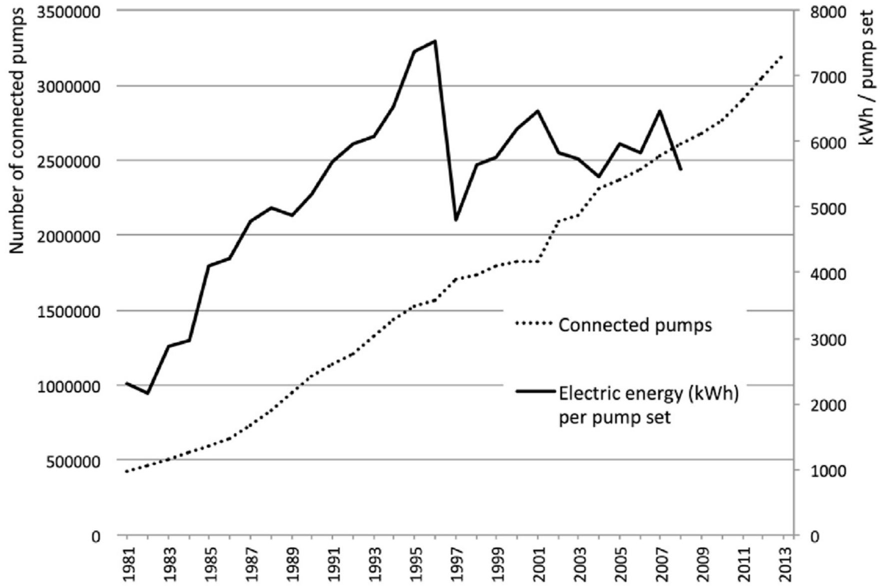

Fig. 1. Connected agricultural services and electric energy consumed per pump set in Andhra Pradesh.
Source: own diagram, based on CMIE (2008) and APTRANSCO (2008).

grid maintenance, contributing to poor power quality and increasing pump set and electricity distribution transformer (DTR) burnout rates (Dossani and Ranganathan, 2004; Kimmich, 2013a).

Extensive research conducted by the World Bank in the states of Haryana and Andhra Pradesh has found that farmers are locked in a "low equilibrium trap." The poor conditions of the infrastructure have led to high rates of motor burnout in agricultural pump sets and resulting repair costs. These costs might even exceed those that would result from a regular, metered, pro-rata electricity price (World Bank, 2001).

This cumulative causation of energy inefficiency and increasing maintenance costs for agricultural power provision has led to a situation where the need for a change in governance seems urgent. Many farmers are willing to pay for electric energy, but only if the quality improves (Dossani and Ranganathan, 2004; World Bank, 2001). Therefore, a better understanding of the low equilibrium trap can contribute toward building a social contract for improving power quality. Pursuing a second best path, by improving the power quality as a means to escape the trap, could facilitate the implementation of a more effective and 'reasonable' (Commons, 1936) solution, for example a unit-based, but viable, and equitable pricing scheme for electricity.

The guiding research questions for this research are: Why has the low equilibrium trap been so persistent despite several policies that have attempted to improve power quality and even though investments seem to promise collectively and individually beneficial outcomes? How can power quality be improved so as to eventually escape the low equilibrium trap?

Lal (2006) has pointed out that "[t]he answer will […] have to be found by placing the pump-using farmer at the center of an analytic work examining the costs and prices of all these inputs and outputs" (Lal, 2006). Along this line, we use game-theoretic models together with survey data to better understand farmers' (strategic) behavior and conditions.

As we point out, several traps along the electricity grid must be overcome to achieve efficient electric energy use. Two key traps are analyzed and a survey is used to calibrate game-theoretic model parameters and measure equilibrium outcomes. We find that coordinated adoption of energy-efficient demand-side technology could improve power quality and mitigate a dilemma resulting from the common-pool characteristics of electric infrastructure capacity. However, overexploitation of capacity can also physically impede the use of technologies to improve power quality, and prevent coordination on a higher power quality equilibrium. The currently observed low equilibrium trap can therefore be explained by two interlinked games. A synthesis of both models yields findings for systemic interventions to overcome the low equilibrium trap.

The article is structured as follows: first, the theoretical approach will be outlined, relating theories of common-pool resource, club good, and network properties and game-theoretic models to the electricity–irrigation nexus, which is a specific manifestation of the more general energy–water nexus. Second, the empirical strategy and methods are described. Third, physical and institutional structures of electricity supply for irrigation and key challenges are briefly explained and two basic game-theoretic models are constructed. Fourth, the empirical findings are summarized, and the survey data is used to bound model parameters. Empirical outcomes are then compared with model predictions. Finally, conclusions and policy implications are drawn and avenues for future research outlined.

2. Theoretical approach

2.1. Common-pool and network properties of electricity provision

The literature on common-pool resources offers analytical concepts, methods, and models that can help to understand and analyze the problems involved in electricity infrastructure governance. Canal irrigation infrastructure, as an engineered system, seems, structurally and conceptually, the most similar infrastructure to electricity (Ostrom et al., 1993). A broad body of knowledge about irrigation infrastructures is readily available concerning the action situations involved in infrastructure governance. The design, finance, construction, use, and maintenance of irrigation infrastructures require a multiplicity of collective actions and related actors, leading to a distinction between action situations for *appropriating* resource units and those dealing with the *provisioning* of the resource system (Ostrom et al., 1994).

Asymmetric access and resource uncertainties are key