Whose appropriate technology? Understanding the adoption of micro-irrigation in the face of climate and policy uncertainty

CARIAA-ASSAR Working Paper

Karan Misquitta and Kalyani Thatte

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About CARIAA Working Papers

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Contact

Collaborative Adaptation Research Initiative in Africa and Asia,
c/o International Development Research Centre
PO Box 8500, Ottawa, ON
Canada K1G 3H9
Tel: (+1) 613-236-6163; Email: cariaa@idrc.ca

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Abstract

In India, drip irrigation is seen as a technology that can address the problem of growing water scarcity while simultaneously increasing productivity and farmer incomes. However, adoption of this technology by farmers remains low; this despite the state providing generous subsidies to promote micro-irrigation.

In this study, focusing on the state of Maharashtra in India, we examine the barriers that farmers face in adopting drip irrigation and how these emerge and persist. Arguing that a technology like drip irrigation must be assessed within the socio-economic, ecological, and institutional contexts that it is situated, we unpack the socio-technical system that has emerged around the technology. Through participatory network mapping and in-depth interviews we delineate the dynamics of this system across multiple scales from the farm-level to state policy and programmes. We also explore how farmers who practice agriculture under highly uncertain and variable conditions, particularly vis-à-vis water availability, take decisions to adopt the technology and how these decisions are affected by pressures that operate across scales. We find that the political economy of subsidy disbursement influences the kind of technology that is promoted and creates barriers to adoption, particularly for relatively resource poor farmers. Further, we find that there exist alternative technologies, which while failing to meet prescribed quality standards and subsequently, falling outside the ambit of subsidy, appear to meet the immediate the needs of this set of farmers.

Our findings are relevant to policy research and design and demonstrate how analysis across multiple scales can yield important information on how and why barriers and enablers to the adoption of agricultural technologies emerge. This is particularly relevant in the context of climate change adaptation where technologies like micro-irrigation are promoted, often without adequate attention to the social, political, institutional, and environmental contexts within which adoption takes place.

About ASSAR

All authors of this working paper are team members in the ASSAR (Adaptation at Scale in Semi-Arid Regions) project, one of four hotspot research projects in CARIAA. The international and interdisciplinary ASSAR team comprises a mix of research and practitioner organisations, and includes groups with global reach as well as those deeply embedded in their communities. The ASSAR consortium is a partnership between five lead managing institutions - the University of Cape Town (South Africa), the University of East Anglia (United Kingdom), START (United States of America), Oxfam GB (United Kingdom) and the Indian Institute for Human Settlements (India) – and 12 partners – the University of Botswana, University of Namibia, Desert Research Foundation of Namibia, Reos Partners, the Red Cross/Crescent Climate Centre, University of Ghana, ICRISAT, University of Nairobi, University of Addis Ababa, Watershed Organisation Trust, Indian Institute for Tropical Meteorology, and the Ashoka Trust for Ecology and the Environment.

Working in seven countries in semi-arid regions, ASSAR seeks to understand the factors that have prevented climate change adaptation from being more widespread and successful. At the same time, ASSAR is investigating the processes – particularly in governance – that can facilitate a shift from ad-hoc adaptation to large-scale adaptation. ASSAR is especially interested in understanding people's vulnerability, both in relation to climatic impacts that are becoming more severe, and to general development challenges. Through participatory work from 2014-2018, ASSAR aims to meet the needs of government and practitioner stakeholders, to help shape more effective policy frameworks, and to develop more lasting adaptation responses.

Why focus on semi-arid regions?

Semi-arid regions (SARs) are highly dynamic systems that experience extreme climates, adverse environmental change, and a relative paucity of natural resources. People here are further marginalised by high levels of poverty, inequality and rapidly changing socio-economic, governance and development contexts. Climate change intersects with these existing structural vulnerabilities and can potentially accentuate or shift the balance between winners and losers. Although many people in these regions already display remarkable resilience, these multiple and often interlocking pressures are expected to amplify in the coming decades. Therefore, it is essential to understand what facilitates the empowerment of people, local organisations and governments to adapt to climate change in a way that minimises vulnerability and promotes long-term resilience.

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About the authors

Karan Misquitta *is a researcher at the Watershed Organisation Trust in Pune.*

Contact: karan.misquitta@gmail.com

Kalyani Thatte *is a graduate student at the TATA Institute of Social Sciences in Hyderabad.*

Contact: kalyani.h.thatte@gmail.com

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1. Introduction

In water stressed regions of India, micro irrigation is seen as an effective technical response for addressing the issue of water scarcity. The material benefits of adoption are well established. Yet in the context of micro-irrigation in India, where large subsidy schemes exist to promote micro-irrigation, the spread of the technology has been slow. In order to understand why such a situation has emerged it is necessary to go beyond assessing the material technology of drip irrigation and unpack the network of actors involved in its promotion and adoption, the socio-economic, politico-institutional, and environmental context under which farmers operate and how these factors together mediate their preferences. In this paper we explore how these factors interact focusing on drip irrigation, which is the most popular technology, over other forms of micro-irrigation (sprinklers, rain guns etc.). We explore how farmers who practice agriculture under highly uncertain and variable conditions, particularly vis-à-vis water availability, take decisions to invest in these technologies. Here the task is not to assess the relative levels of adoption of drip irrigation at a national or community scale, but rather to understand farmers' decisions to invest in drip irrigation and their choice of a particular technology. We delineate the political economy of subsidy disbursement to show how barriers emerge that make it difficult for resource poor farmers to access the subsidy. Further we find that these farmers opt for low cost drip irrigation (LCDI) technologies, which are unsubsidized, but help them to meet their immediate the needs.

In India the national discourse presents micro-irrigation as a solution to the issue of water scarcity in the country. The promise of more crop per drop is invoked as an answer to the challenge of managing limited natural resources sustainably while simultaneously increasing production and incomes (The National Institution for Transforming India [NITI] Aayog, 2017). Over the past three decades drip irrigation has spread considerably in India from only 71,000 ha in 1992 (Indian National Committee on Irrigation and Drainage (INCID), 1994) to over 3.3 mha in 2015 (Global Green Growth Institute (GGGI), 2015). Estimates of ultimate potential for micro-irrigation such as drip, sprinklers, and others, vary widely. Conservatively this has been estimated to be 7.98 mha (Kumar, 2016), while the task force on micro-irrigation optimistically pegs this figure at 97 mha (Narayanamoorthy, 2016). Most assessments however, place this figure between 18 - 27 mha (Awasthy et al, 2014; Narayanamoorthy, 2008a; Palanisami et al., 2011). Regardless of the true potential, it is clear that the actual area covered under drip irrigation lags behind potential to a considerable degree.

The expansion of micro-irrigation in the country has also been accompanied by the accumulation of a large body of research. The literature on the adoption of micro-irrigation in general and drip irrigation in particular in India has focused primarily on impacts on production and income at the farm level (Kumar & Palanisami, 2011; Narayanamoorthy, 2004; Palanisami et al., 2002). Under drip irrigation, increases of up to 88 per cent and reduction in water applied between 36 and 68 per cent in various crops have been reported (National Committee on the Use of Plastics in Agriculture (NCPA), 1990). Positive benefit-cost ratios (BCR) have been reported for a variety of crops, with widely spaced in orchard crops showing the best results (INCID 1994; Narayanamoorthy, 2008a; Reddy & Reddy 1995). Gains in water use efficiency arising from drip irrigation also enables the expansion of irrigated area and by reducing need for weeding and savings in fertigation drip irrigation leads to substantial reductions in cost of cultivation (INCID, 1994; Shah & Keller, 2002; Singh & Jain, 2003). Drip irrigation can also result in considerable savings in energy (Global AgriSystem, 2014;

Narayanamoorthy, 1996) and labour (Kumar & Palanisami, 2011; Narayanamoorthy, 2016). Given the slow spread of drip irrigation researchers identified the physical, socio-economic, and politico-institutional constraints on the spread of micro-irrigation (Kumar et al. 2008a). Research has identified factors that affect adoption such as socio-economic characteristics of farmers (caste, education, landholding size), crop choice, etc. (Namara et al. 2007; Palanisami et al. 2011) as well as barriers and constraints to adoption the such as high capital costs, lack of credit, and low levels of awareness (Dhawan 2000; Kumar, 2016, , Narayanamoorthy, 1997, Sivanappan 1988).

To encourage the adoption of drip irrigation and responding to the high capital costs associated with adoption, subsidy schemes have been in place in the country for many decades, beginning from 1982 (Narayanamoorthy & Deshpande, 1997). More recently the National Mission on Micro-Irrigation (NMMI) launched in 2009 aimed to bring an additional 2.85 mha under micro-irrigation (GGGI, 2015). This programme was later subsumed under the National Mission for Sustainable Agriculture 2014-15 and then the *Pradhan Mantri Krishi Sinchai Yojana* in 2015-16 with the total outlay on micro-irrigation between 2009 and 2015 amounting to Rs. 57.89 billion (Kapur et al, 2016).

While large-scale subsidy schemes have been in play for several decades, their performance and the particular political economy that drives them has only recently begun to receive attention in peer reviewed literature. Assessing the impact of drip irrigation, Narayanamoorthy (2016, 2008b, 2004) finds that with the provision of subsidy, the BCR also increased considerably for key crops, indicating that subsidy plays a positive role in improving the economic viability of drip irrigation. However, few studies have evaluated how these programmes, which have displayed considerable diversity in their design and implementation, have performed. While these schemes are driven by funding from the central government, the actual implementation of the programmes is carried out by the respective state governments, with some state governments, such as Maharashtra and Gujarat, having their own schemes as well. It is thus important to focus attention on the role played by the design and implementation of these programmes. The experience of subsidy schemes in Gujarat and Andhra Pradesh suggests that the design of the programme itself can shape adoption (Bahinipati & Viswanathan, 2016; GGGI, 2015, Pullabhotla et al, 2011). Subsidy schemes also influence the kind of drip technologies that are promoted, driven by the need to monitor the quality of the drip sets. This has resulted in the promotion of high quality and durable drip irrigation systems, that while meet exacting quality standards, are also relatively expensive (Benouniche, 2014b; Venot et al, 2014). This can also create perverse incentives where rather than rather providing services to farmers, manufactures and providers are encouraged to engage in rent-seeking from the state (Malik et al, 2016).

Market and other mechanisms have also responded to the high capital costs associated with drip irrigation through the development of low cost drip irrigation (LCDI). Agri-business in India is a dynamic sector, with a history of innovating and translating technologies to local needs (Herring, 2006). In the context of drip irrigation, innovations were driven by farmers in Maharashtra and Madhya Pradesh in response to water scarcity as well as the prohibitive costs associated with conventional drip irrigation (Keller & Shah, 2002; Verma et al, 2004). The LCDI segment has also seen high levels of involvement from the NGO sector, with NGOs like International Development Enterprises playing a central role in formalizing and improving the technology (Heierli, 2000). LCDI has been promoted across the developing world, particularly in Africa, as a poverty alleviation tool targeted towards smallholders (Burney & Naylor, 2012; Friedlander et al., 2013; Venot, 2016). In

India however, aside from interest at the outset, little research has emerged on LCDI, even though it has emerged as a dynamic and growing segment of the market, with a large number of players, from local enterprises to the largest manufacturer of micro-irrigation technologies in the country (GGGI, 2015). While LCDI sets are increasingly popular, this market has emerged distinct from the subsidy regime as they do not meet prescribed quality standards and are not eligible for inclusion.

2. Conceptual Framework

A reason for the lack of attention to the larger milieu within which a technology like drip irrigation is adopted is linked to a particular view of technology that focuses attention on its material aspects and technical characteristics divorced from the environment and context in which it is promoted. While the traditional model that is used to explain the diffusion and adoption suggests that a technology is invented and then simply transferred to new sites where it is adopted or rejected, more recent scholarship challenges this perspective and highlights how feedback and innovations originating from end users can transform a technology (Garb & Friedlander, 2014; Soete, 2014). This is particularly relevant in the context of micro-irrigation where innovations in low cost drip irrigation have been driven by end users (Benouniche, 2014b; Keller & Shah, 2002; Verma et al, 2004).

If the benefits of drip irrigation and the challenges associated with adoption are, as we argue, linked to the context of use rather simply to the hardware itself, then the question of the best technology becomes a series of questions: “for whom is this technology the best technology? When is this best technology? How is this the best technology? And so on” (Garb & Friedlander, 2014, p. 14). To answer these questions, the focus of investigation shifts away from the material technology of micro-irrigation such as drippers, laterals, filters, and so on, towards delineating the networks of actors, actions and practices through which the materiality of a technology like drip irrigation is realized (Venot et al., 2014).

Jansen & Vellema (2011) propose *technography* or the ethnography of technology as an appropriate approach to studying these networks of actors or socio-technical systems. Technography emphasises “how tools and techniques are performative and situated, distributed, and dependent on institutions”, and presents a way to study how these are developed and used within particular social contexts. (Garb & Friedlander, 2014, p15). While technography emphasizes the network of actors and contexts that constitutes the larger socio technical system, it also places the user at the centre of this network. Influenced by Richards’ (1993, 1989) work on agriculture as performance, it emphasises the social and environmental contingencies that farmers operate under and respond to. It highlights the role of spontaneity rather than purely deliberative planning, where farmers take decisions through their “improvisational capacities called forth by the needs of the moment” (Richards, 1993, p. 62). The metaphor of performance suggests that faced with unpredictable environmental conditions, farmers respond by adjusting their actions in time and in place, rather than pre-planning their activities using scientific methods (Kumar R., 2016). Here the focus is on farmers’ agency, particularly on how this agency influences and responds to the dynamic social and ecological contexts (Crane et al., 2011). This draws our attention to how farmers’ preferences shape technological adoption and how these preferences are in turn shaped by their socio-ecological context. This shifts analysis towards delineating the actual conditions in which drip irrigation is implemented in order to understand how farmers make decisions regarding the adoption of particular agricultural practices (Benouiniche et al., 2014a).

In approaching drip irrigation as a socio-technical system, an important line of inquiry follows from work on the spread of green revolution technology in India. It has been argued that the technology promoted through the green revolution was scale neutral (Birner & Resnick 2010; Hazell et al. 2010; Mosley, 2002). This however does not mean that they were resource neutral (Bernstein 2010, Harris 1988) and Byres (1981) argues that class plays a role in determining access to technology and which in turn affects the process of social differentiation.

In order to operationalize this approach, we turn to recent developments in literature on adaptation that move away from simplistic unilinear models of technology adoption and stress that agricultural decision making is influenced not only by circumstances at the farm or household level but also processes that unfold at multiple scales from the local to the national level (Feola et al., 2015, Singh et al., 2016,). We use a conceptual model developed by Feola et al (2015; see Figure 1), which is useful for understanding a socio-technical system such a micro-irrigation. The model identifies three key areas of knowledge: a farmer level decision making model; cross-scale and cross-level pressures; and temporal dynamics. This is consistent with a technographic approach which, while emphasizing a farmer centric perspective, also casts light on how actors and networks operating across scales and their specific interests and motivations constrain and influence decisions at the farm level. The third area of temporal dynamics is also essential for understanding how technological adoption takes places as it draws attention to processes by which technologies are translated into local contexts as farmers experiment with available technologies (Verma et al., 2004), learn from their own experiences as well as those of their peers (Foster & Rosenzweig, 1995), and adapt them to their specific needs and capacities (Benouniche, 2014a; 2014b).

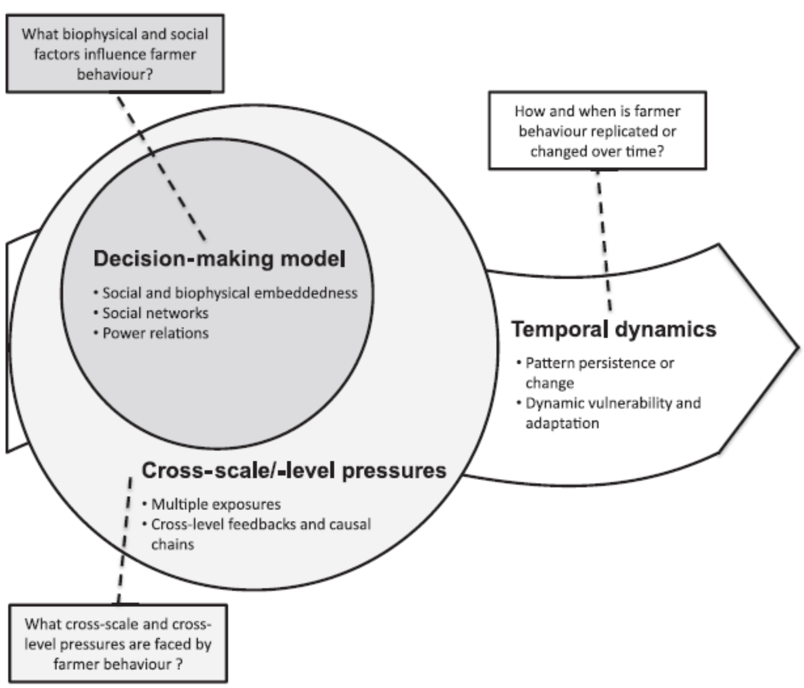

Figure 1: The three areas of knowledge as presented in Feola et al 2015.

3. Data and Tools

Our assessment of drip as a socio-technical system employed the following tools: (i) participatory mapping of the subsidy process, (ii) key informant interviews, (iii) semi-structured interviews with drip irrigation users, and (iv) arguments drawn from the analysis of documents and secondary data related to micro-irrigation.

As argued in the previous section drip irrigation can be seen as a socio-technical system in which a network of actors interact at various levels, with state sponsored subsidy schemes playing a pivotal role. In order to map out the subsidy process and the network of actors and interactions involved we used a modified version of the participatory mapping tool, NetMap (Schiffer, 2007). NetMap was developed to map out a socio-economic network where actors, their links, and their roles are reflected (Schiffer, 2013; Schiffer and Hauck, 2010). An extension of the tool, "*Process NetMap* (Latynskiy & Berber, 2015; Raabe et al., 2010), allows researchers to capture a dynamic network by asking interviewees to identify interactions between actors and is more appropriate for understanding how the subsidy process actually unfolds. We conducted five NetMap sessions with drip irrigation users in five villages, during these sessions farmers described the process as they experienced it and identified key actors, bottlenecks & barriers. A gap that emerged through the NetMap exercise was that farmers lacked knowledge about how the process unfolded at higher levels, i.e. at the levels of the block, district administration and above.

Interviews with key informants representing different stakeholder interests and administrative levels vis-à-vis the micro-irrigation regime were conducted to address this gap. These stakeholders were identified through the NetMap exercises as well as from relevant policy documents and guidelines. In total, 12 semi-structured interviews were conducted with key actors in the network: officers at various levels of the administration from the village to the state level. Twenty open ended, semi-structured interviews were conducted with farmers in the study villages who used drip irrigation. These farmers were selected randomly from lists of drip irrigation users that a local NGO had prepared. Of the farmer interviews, 11 farmers used drip sets that they had purchased under the subsidy scheme while nine farmers used LCDI sets purchased.

Additionally, fieldwork also benefitted from numerous informal interactions that took place on the sidelines of focus group discussions, Panchayat offices, and at agricultural supply stores. These informal sessions, or hanging out (Roy, 2013; Wogan, 2004) often provided more insights than the structured discussions themselves and opened up new lines of enquiry.

Table 1: Overview of interactions with farmers

Village	**NetMap**	**Farmer Interviews**	
		ISI	LCDI
Warudi Pathar	Yes	-	-
Khandgedara	Yes	-	-
Kauthe Khurd	Yes	-	-
Sarole Pathar	Yes	4	5
Gunjalwadi	Yes	4	3
Dolasne	-	3	1

4. Study Area

Fieldwork was conducted across a cluster of six villages (figure 2) in the Sangamner block of Ahmednagar district in Maharashtra. We selected the cluster as it captured a high degree of heterogeneity within a small area that is representative of the region as a whole. The cluster lies in the rain shadow region of the Western Ghats and often experience drought, with an average annual rainfall of 565mm and high inter-annual variation. While the villages are contiguous, there is considerable heterogeneity between them. Broadly the cluster can be divided into two regions: a narrow strip of irrigated land in the valley carved by the Mula River and a plateau region. Water is abundant in the valley portion owing to the presence of the Mula River which flows throughout the year. The plateau or *pathar* region on the other hand is rainfed and characterised by water scarcity. The underlying aquifers here are hardrock with massive basaltic sheets that have little storage capacity (Thomas & Duraiswamy, 2016). Wells and borewells generally dry up with the onset of summer as a result of increasing groundwater draft as well as water discharging out of the aquifers as it makes its way to down the valley. The valley area is dominated by pomegranate orchards and irrigated vegetable crops such as onion and tomato, while in the *pathar* region, rainfed onion, pearl millet, and jowar dominate. Farmers with access to water in the *pathar* region however also grow irrigated onion, tomato, and pomegranate, owing to their higher value. In the last decade, an increasing number of pomegranate orchards have begun appearing in the *pathar* region.

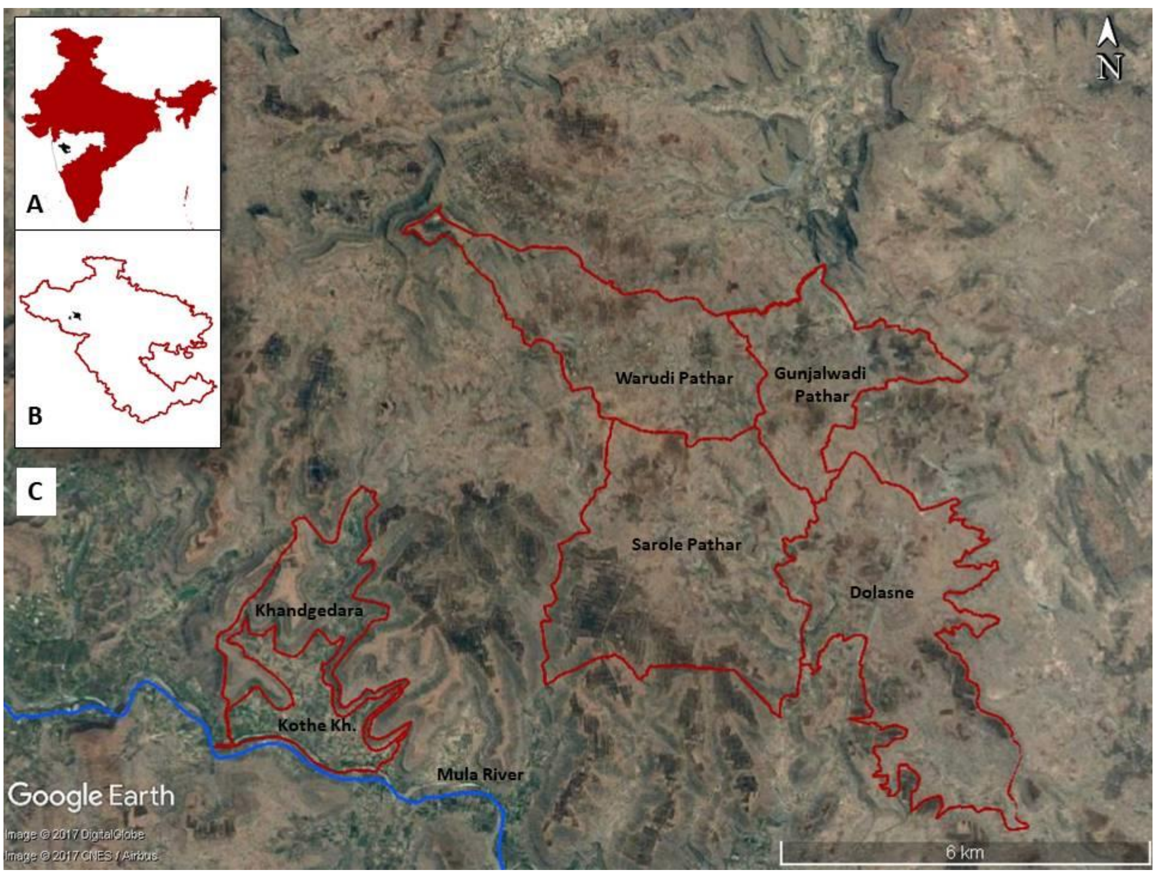

Figure 2 A: Location of Ahmednagar district (black) within India. **B:** Location of Study villages within Ahmednagar District. **C:** Study Villages (red outline) and Mula River (blue)

Over the years, government and non-governmental agencies have made several attempts to tackle the problem of water scarcity in the region. Even with the implementation of watershed programmes and other developmental interventions, water scarcity remains an issue, owing to recurrent drought, the underlying hydrogeology, and increasing levels of groundwater abstraction (Thomas & Duraiswamy, 2016). Over the last few decades, increases in the use of groundwater for irrigation has resulted in groundwater over-exploitation in many blocks in the Ahmednagar district, including Sangamner. The estimated groundwater draft in Sangamner was 96.5% of total availability in 2011 (Central Ground Water Board, 2014), with 106 of 169 villages in the block designated as semi-critical, critical or over-exploited (MWRRA, 2015). The increasing reliance on groundwater has been accompanied by a shift in cropping patterns from millets and groundnut to higher value crops like onion, tomato, and other vegetable crops. The relative proximity of the region to the urban centres of Pune, Nashik, Mumbai and Ahmednagar ensures the high demand for these crops. Labour is also increasingly scarce in the region as the younger generation begin to leave the household in search of work in urban centres. These shifts, namely the changes in cropping patterns, reduced labour availability, and high levels of water scarcity have created conditions under which drip irrigation becomes an attractive option for farmers.

5. Results and Discussion

5.1. Drip irrigation technology and actors

In this section, we delineate the variety of technologies available and network of actors that constitute the drip-irrigation socio-technical system (see figure 3). As mentioned earlier the presence of a subsidy can influence the type of drip irrigation technology that is promoted. By virtue of being a large-scale subsidy scheme, the programme guidelines dictate particular norms and specifications for the material that is used in order to ensure that certain quality standards are met and that public funds are used to invest in durable and lasting material. This however means that these drip sets, which receive the bureau of Indian Standard’s ISI mark, are relatively expensive. Besides these “ISI” certified sets there exist low cost drip irrigation (LCDI) alternatives that are not covered under the subsidy. These can be broadly divided into two types: Non-ISI certified sets which have most of the features of the ISI certified sets i.e. inline or online drippers installed in the laterals but are of low quality and “pepsee” sets which consists of low density polythene piping which are perforated rather than having drippers. For the purpose of the paper we club both these types as LCDI. The approximate costs of these systems for the major crops in the region are given in table 2. Drip irrigation has been shown to provide the best results in widely spaced, high value, perennial crops, like fruit orchards etc (Kumar, 2016, Kumar et al 2008b). In Maharashtra it has historically been seen as a ‘Gentleman’ farmer’s technology, best suited for orchards and plantation crops in relatively larger establishments (Verma et al 2004; Shah & Keller, 2002). In Maharashtra most of the area covered under drip irrigation under the subsidy scheme is for widely spaced crops such as cotton, sugarcane, and fruit orchards like Pomegranate, Banana, Orange and Grape (Figure 4). In later sections we argue that this is also closely linked to the nature of the particular technology that is promoted and the process by which it is promoted.

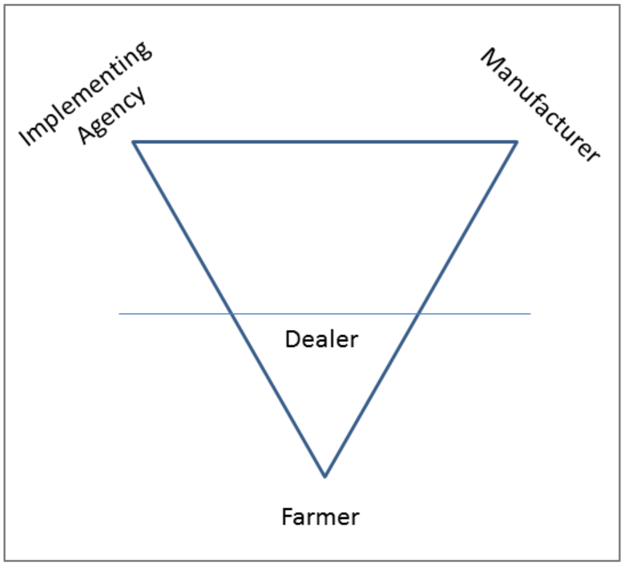

Figure 3: Schema of actors in micro-irrigation socio-technical system

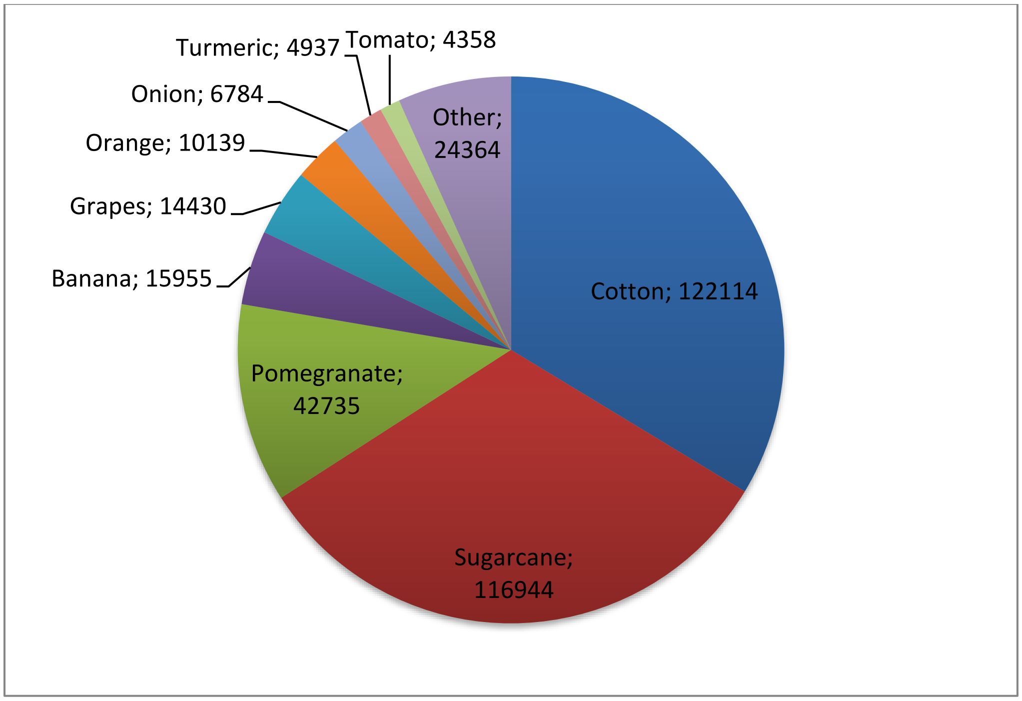

Figure 4: Crop area covered (ha) under drip irrigation schemes from 2011-2016 in Maharashtra (Source: http://mahaethibak.gov.in/mahdrip/ethibak/index.php retrieved 6th Sept 2016)

Table 2: Approximate per ha cost of different drip technologies for major crops (amount in Rupees) (Source: Authors field notes)

Crop	ISI (Rs.)	LCDI (NON ISI) (Rs.)	LCDI (PEPSEE) (Rs.)
Pomegranate	18-20000	10000	-
Tomato	45-50000	20000	12000
Onion	45-50000	20000	12000

Users

Drip irrigation is not appropriate for all farmers, in order to take advantage of drip irrigation a farmer must have access to irrigation and grow appropriate crops. However, as we point out below there is still considerable heterogeneity amongst users, based on landholdings, financial resources, and levels of access to water. Disaggregated data on drip irrigation adoption is not easily available. However, the data from micro-irrigation subsidy schemes in the state reveals important information regarding the characteristics of farmers who avail of drip sets through the subsidy scheme. Between 2010-2016 almost six hundred thousand farmers received subsidies for micro-irrigation, with drip irrigation being by far the most popular technology, accounting for 71% of beneficiaries and 86% of total expenditure, and sprinkler irrigation accounting for the rest. Here we can see that much of the demand for micro-irrigation, comes from farmers with larger landholdings. While marginal holdings constitute 49% of the total individual landholdings in the state, marginal farmers account for only 25% of beneficiaries. Caste related statistics are revelatory, scheduled castes (SC) and schedule tribes (ST) constitute 11.4% & 9.2% of the state population respectively (Census of India 2011), however as seen in table 3 & table 4, only 2% and 1% of beneficiaries. Thus, the benefits of drip irrigation appear to accrue to upper caste groups and large landholders. Only a small fraction of marginal and small farmers in India have access to irrigation through their own irrigation wells, an almost necessary condition for drip irrigation, while 69% of large farmers have their own wells (Kumar et al 2013). This coupled with the higher capital endowments of large farmers, means that they are best placed to invest in drip irrigation and thus take advantage of the subsidy. Regarding caste, successive scheme guidelines have outlined that 24% of funds be spent for SC & ST farmers but have failed to meet this target by a wide-margin. During discussions with farmers from these groups in the study villages a twofold explanation for this emerged. SC & ST farmers in the region tend to have small and marginal landholdings and few of them have access to any reliable source of irrigation. Second, they appeared to have low levels of knowledge of how the schemes worked compared to farmers from the Maratha community, the dominant upper caste group in the study area.

Table 3: Landholding beneficiaries of micro-irrigation schemes
(Source: http://mahaethibak.gov.in/mahdrip/ethibak/index.php retrieved 6th Sept 2016)

Landholding Group	Beneficiaries		
	Drip	Sprinkler	Total
Marginal	26%	22%	25%
Small	45%	57%	48%
Other	30%	21%	27%

Table 4: Caste beneficiaries of micro-irrigation schemes
(Source: http://mahaethibak.gov.in/mahdrip/ethibak/index.php retrieved 6th Sept 2016)

Caste Group	Beneficiaries		
	Drip	Sprinkler	Total
General	82%	57%	75%
OBC	14%	36%	21%
SC	1%	3%	2%
ST	1%	2%	1%
Other (Institutes)	1%	2%	1%
Disabled	0%	0%	0%

Manufacturers

Manufacturers can broadly be divided into those that produce ISI certified drip sets that qualify for subsidy and those that produce only LCDI sets that are not ISI certified and therefore do not qualify for subsidies. It should be noted that the first group of manufacturers have now also begun making LCDI, non-ISI certified, sets. In Maharashtra, 101 manufacturers sold drip sets under the subsidy scheme between 2012 and 2016. However, the market is dominated by a few manufacturers, with the Indian giant Jain irrigation accounting for 43% of subsidy and Israel's Netafim accounting for another 12%. During this period Jain Irrigation effectively received Rs. 677 cr by way of subsidy (See Figure 5).

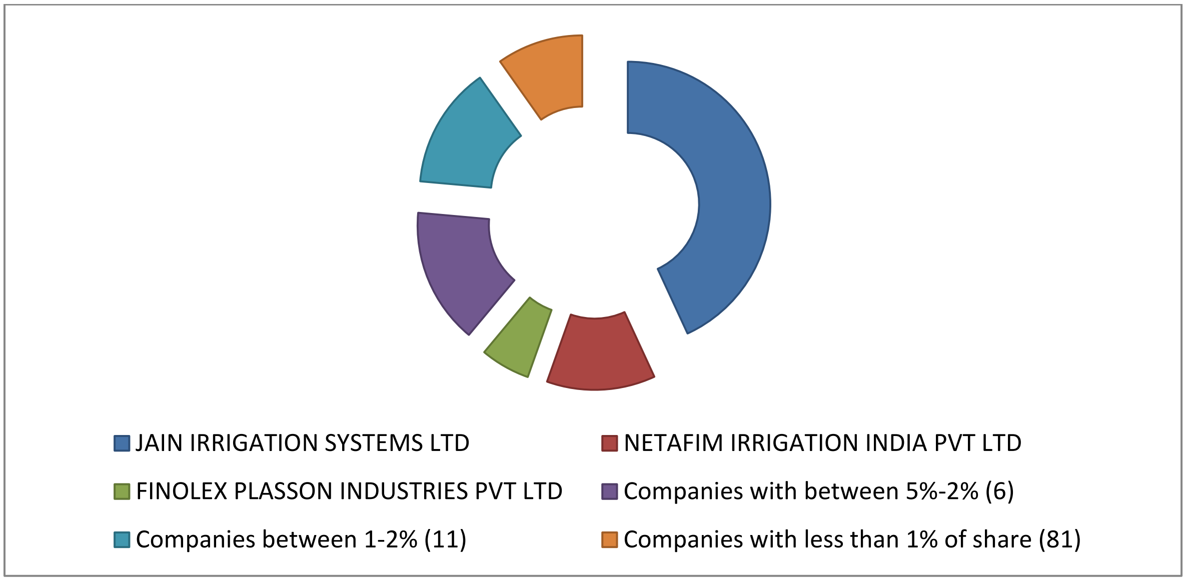

Figure 5: Effective distribution of subsidy among manufacturers
(Source: http://mahaethibak.gov.in/mahdrip/ethibak/index.php retrieved 6th Sept 2016)

Implementation agencies

In Maharashtra, this role is played by various tiers of the agricultural department, banks as providers of credit are also potentially important. Maharashtra is one of the largest recipients of central government funding under micro-irrigation schemes. Under the scheme farmers are entitled to receive a subsidy equivalent to 50% of the cost of the drip set. This provision is increased to 60% for smallholder famers and marginalized groups. The department oversees all stages of programme implementation from assessing the total demand and applications, to verifying and finally disbursing the subsidy to farmers.

Retailers

Closely linked to the manufacturers & the implementation agency are the retailers, who must register themselves in order to sell drip sets under the subsidy process. These retailers mediate between farmers and the manufacturers by providing information on available sets, and costs etc. They also mediate between farmers and the implementing agency by assisting farmers in applying for the subsidy. Here also there is considerable diversity in the kinds of retailer, on the one hand there are large dealerships which are registered with the implementation agency and sell sets under the subsidy scheme while on the other hand there are many small agricultural supplies stores that sell drip sets outside of the subsidy scheme.

5.2. Cross-scale and cross-level pressure

In order to understand how the programme actually unfolds on the ground and if and how it diverges from the process outlined in the guidelines we conducted NetMap sessions with five groups of farmers. Figure 6 & Table 5 presents a final NetMap compiled from information gathered from project guidelines, the NetMap sessions, and key informant interviews, with the red highlights representing hotspots, that is bottlenecks and barriers that emerge in the process.

Unpacking micro-irrigation subsidies

In Maharashtra, the micro-irrigation subsidy scheme is implemented by the State Agricultural department. Funds are provided through a centrally sponsored scheme with the government of Maharashtra also contributing its own funds. The process by which allocations and fund disbursements are made is outlined in Table 5 & Figure 6. As per implementation guidelines that are issued from time to time the programme unfolds in the following manner: A farmer who is interested in installing a drip irrigation set fills an online form with the details of the set required, the crop, area to be covered etc. This is then scrutinized by the block level authority and a pre-sanction is given, based on the availability of funds and the merit of the farmer's application. The farmer must then approach a registered dealer/supplier of his choice within a stipulated time period and purchase the drip set, making the full payment upfront and submitting relevant documents to the dealer who then passes on the application along with these documents and bills to the block level authority. In the mean-time the set is installed in the farmer's field by the supplier. The local agricultural assistant then inspects the farmer's field and checks whether the billed items match with the actual set that was installed. If everything is in order, the report is sent back to the block level authority, and then up to the district level authority. After a process of scrutiny at various levels a payment is sanctioned and then the subsidy amount that the farmer is eligible for is deposited in his account. This process should be completed within six months.

During conversations with farmers the primary grievance that emerged was associated with the requirement that the farmer must pay for the entire drip set and then wait for a long period to receive the subsidy amount in the form of re-imbursement. Farmers who had purchased drip sets in 2013 complained that they still hadn't received their share of the subsidy.

It is important to note that the subsidy regime was overhauled in 2012. Under the earlier system farmers were required to only make their share of the payment to the supplier, and then the subsidy component was transferred directly to the manufacturer. However, under this system there was wide space for malpractices to thrive, with suppliers over-invoicing the sets and claiming inflated subsidies. Another reason behind the overhaul of the subsidy scheme was the upward pressure that the old subsidy system exerted on the prices of drip sets. Here manufacturer, when faced with large delays in the between the sale of a set and the disbursement of the subsidy, internalized the costs associated by raising the prices of the drip sets. The new scheme design resolved these problems by introducing a fixed pricing policy and requiring the farmers to pay the full price at the time of purchasing a set.

Another major change took place in 2013 when the government shifted the application process online. This was precipitated by the need for more transparency in the application process. Under the earlier regime potential for corruption entered the system owing to the discretionary power vested in lower level officers in processing the applications through a manual process as the number of applications frequently exceeded the funds available. This meant that there was some ambiguity as to why some applications were processed while others delayed. In the new system the list of beneficiaries (pre-sanction) is prepared on a first come first served basis which is easy to track as the applications are made online. However, this has not necessarily resulted in more transparency. Computer literacy is quite low among farmers in general. This means that they have to rely on others to access the online process, a role that is naturally filled by the dealers themselves. These dealers have little interest in the back and forth associated with the process of pre-sanction etc. and do not inform farmers about this. In fact, during the NetMap sessions the entire process of pre-sanction did not appear in any of the process maps developed. In practice farmers purchase the system outright and then the application process is initiated by the dealer. In a given year there are more applications for subsidy than are actually sanctioned. However, this is not clear to farmers who apply for subsidy, who have to wait for long periods, as their applications remain on a waitlist until funds are available. Thus, farmers purchasing drip irrigation sets, do so without a guarantee over whether they are eligible to receive the subsidy in the year that they apply.

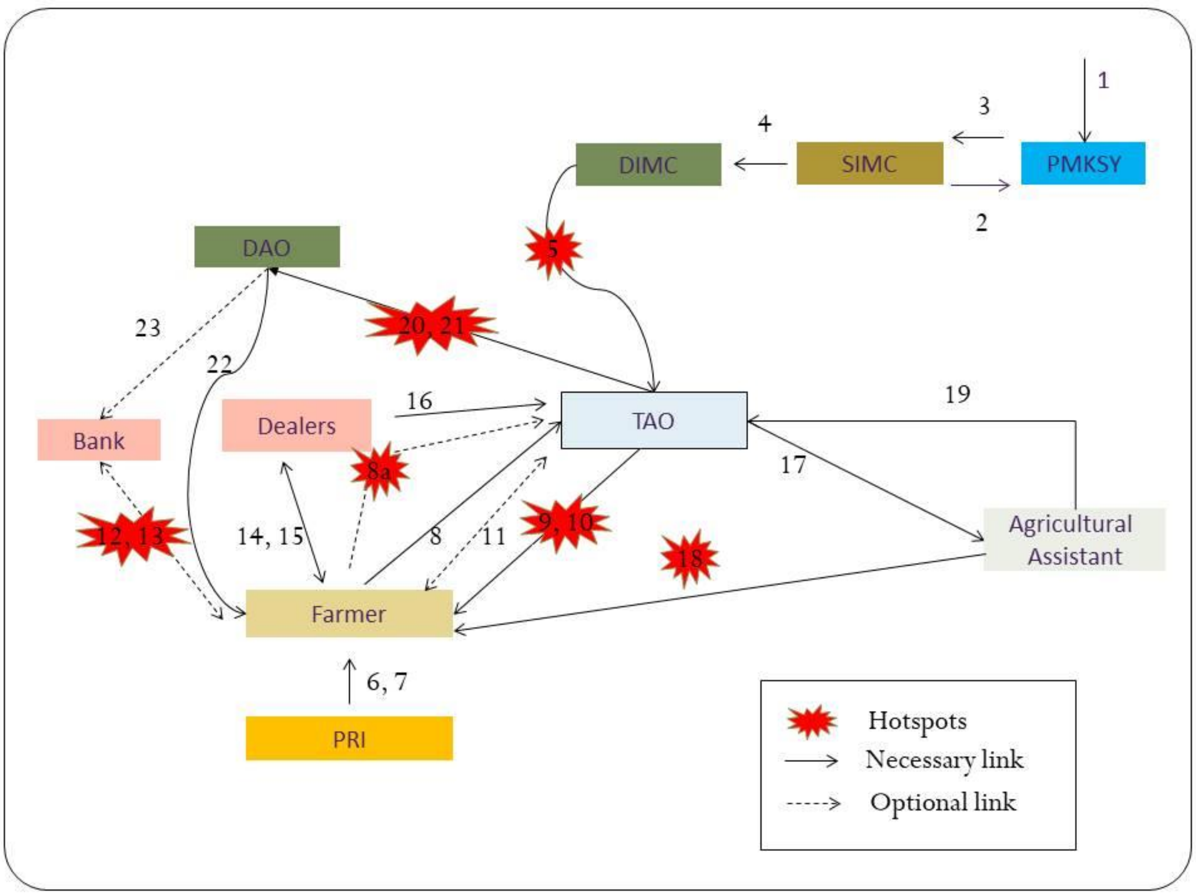

Figure 6: Compiled process NetMap of the subsidy disbursement process (see table 5 and table 6)

Table 5: Aggregate NetMap of drip irrigation subsidy process in Maharashtra

The Micro-irrigation (MI) Subsidy Process in Maharashtra	
1. Funds are allocated fund for MI programme under PMKSY by the Central Government. 2. State Micro-Irrigation Committee (SIMC) sends its State Action Plan (SAP) to centre. 3. Centre releases funds to every state according to SAP. 4. Funds are allocated to each District Micro-Irrigation Committee (DIMC) by the SIMC in accordance with the demand 5. Funds are allocated to each Taluka/Block Agricultural Officer 6. Panchayati Raj Instituions (PRI's)I & Govt Agencies promote the MI programme. 7. Farmer makes a decision to apply subsidy for MI 8. Farmer fills online application (individually or via dealer) (8a) 9. Based on fund availability pre-sanction is given by the Taluka Agricultural Officer (TAO), other applications are put on a waiting list 10. Farmer receives pre-sanction 11. Farmer Approaches TAO for bank loan sanction	12. Farmer applies for bank loan 13. Farmer Receives loan 14. Farmer approaches dealer of his choice and purchases a set & Submits all documentary proof required. 15. Dealer installs the drip irrigation set in the farm 16. Dealer completes online form & submits farmers file to TAO 17. TAO officer scrutinizes all forms received and release the beneficiary list and send it to Agricultural assistant 18. Agricultural assistant or circle agricultural officer completes the spot verification 19. Spot verification report is sent to the TAO. 20. Applications are verified by TAO and District Agricultural Officer (DAO) 21. Recommendation for subsidy is cleared by the DAO 22. Subsidy is deposited in farmers bank account 23. In cases where farmer has obtained loan the subsidy amount is deposited in a fixed deposit controlled by bank

Table 6: Hotspots and barriers identified through the NetMap exercise

Hotspot Identified	Description
5	Allocation of funds to the Taluka level is often delayed. While funds are sanctioned, disbursement takes a long time
8a	Farmers are generally unaware of the details of the online application process and rely heavily on dealers and retailers to guide them through the process
9, 10	There is low awareness that only applications that receive pre-sanction are eligible for the subsidy. Farmers purchase drip sets before receiving this pre-sanction as dealers are only willing to manage their applications after they make their purchase
12, 13	Banks are reluctant to make loans to farmers for purchasing drip irrigation sets as the amount is low and are farmers have poor reputations for repaying loans. Most farmers arrange credit from other sources, i.e. relatives, peers and money lenders
18	The spot verification is often delayed as agricultural assistants are unable to process the number of applications that they receive
20, 21, 22	While funds are sanctioned, actual disbursement is delayed. Delays occur at various level, centre,-state, district. A key reason for the delays is the back log from previous years. The migration to an online system has purportedly reduced the delays in allocation

Actors and interests

The constraints that influence the design of a subsidy regime also have consequences for the way that technological adoption unfolds on the ground. When faced with problems of transparency and corruption the government of Maharashtra chose to restructure the subsidy. While this addressed the issues at hand it is important to understand the implications of this for the other actors who operate within the network. The first consequence is that it created a barrier to adoption by requiring farmers to pay the full cost of the drip set up front. While in theory this should not matter as the farmer will eventually receive her share of the subsidy, the high initial capital costs coupled with the long delays that farmers experience when receiving the subsidy has meant that poorer farmers are reluctant to invest. Further resource poor farmers generally grow crops (onion & tomato) that require a higher density of laterals, this makes the investment required for a drip even higher. Again, the migration to an online system was made to make the subsidy process more transparent. However, it is important to recognize that by itself this does not necessarily amount to making the process easier for beneficiaries and that leveraging technology to improve scheme implementation and benefit delivery is not a panacea (Khera, 2016). Dealers, manufactures and officials that we spoke to identified the shift towards farmers having to pay the full cost of the drip sets upfront as providing space for the expansion of the LCDI segment, while a host of factors may have contributed to this, such as declining groundwater levels, the entry of major manufacturers into the segment, data from the study villages appears to support this as LCDI only began expanding in 2013 after the shift in policy (see figure 7).

The responses that Maharashtra has chosen is not the only possible way to address problems associated with the implementation of drip irrigation subsidies. Gujarat's subsidy scheme presents an alternative. A major innovation in Gujarat is the creation of a special purpose vehicle, the Gujarat Green Revolution Company (GGRC). In Maharashtra on the other hand the Department of Agriculture oversees programme implementation. As compared to the Agriculture Dept. which has multiple mandates, the GGRC, as an SPV, is able to ensure smoother implementation it is able to dedicate more of its resources to the implementation the subsidy scheme. Another key difference is that in the case of Gujarat, the farmer is required to make only her share of the payment to the GGRC, which then releases an advance to the manufacturer, and makes a full payment (the farmers contribution +subsidy component) to the manufacturer only after the drip set has been delivered to the farmer. This lowers the upfront costs that the farmer is faced with. It also has another important consequence, as under this system as well the processing of payments are slow and manufacturers experience delays in receipt of payments (Kapur et al, 2016; Pullabhotla et al 2012). This means that the costs associated with delays in payments are borne by the manufacturing, unlike in Maharashtra where they are borne by the farmer.

Over subscription is a problem that has plagued micro-irrigation subsidy schemes in states across India. However, the design of the subsidy scheme itself has consequences for how this problem affects actors in the network. In Gujarat & Andhra Pradesh, payments to the manufacturer are made by the implementation agency rather than to farmer. These payments are made after the set is installed on the farmer's field. Here if the implementation agency processing applications in the absence of funds, the manufacturer, must wait for funds to become available before it receives funds

(Kapur et al 2016). This has created considerable dissatisfaction among manufacturers, for whom on the one hand subsidy generates demand for drip sets while on the other hand delays in payments affect their margins and operating costs. A strategy paper commissioned by the Federation of Indian Chamber of Commerce & Industry (FICCI) and the Irrigation Association of India (IAI)[1], argues for restructuring the subsidy process in the form of a direct transfer benefits scheme so as to reduce these problems (Kapur et al., 2016). In Maharashtra the present regime closely resembles the one proposed by FICCI. Yet over subscription & delays persist in this system as well. However here, the burden of the delays, experienced as opportunity and transaction costs shift from the manufacturer to the farmer.

5.3. Farm-level decision making: Planning and performing agriculture in Sangamner

In this section, we move from the wider policy environment in which drip irrigation is promoted to the dynamics and patterns of adoption at the field level. Here we use the notion of performance in the context of agriculture to understand how farmers take decisions to invest in drip irrigation and why they choose a particular technology over the other, while also making explicit the role that a farmers' resource endowment plays in determining these choices.

The literature on drip irrigation shows that that the best benefit cost ratios are achieved when drip irrigation is applied to high value perennial orchard and plantation crops (Narayanamoorthy, 2008a). A reason for this is that as these crops tend to be quite widely spaced and as a result significantly fewer laterals are required per unit area. On the other hand relatively less widely spaced seasonal crops like onion and tomato require a higher density of laterals which raises the per unit area cost considerably (see table 2 for approximate costs). In the cluster of villages studied ISI sets were primarily used for pomegranate orchards while non-ISI LCDI sets were primarily used for seasonal crops such as onion & tomato (see table 7). The characteristics of these technologies and their appropriateness for different crops that emerged from the NetMap FGDs & farmer interviews are summarized in table 8.

Table 7: Crop area under ISI & LCDI sets in study villages (Source: WOTR)

Type of Drip Set	Crop (area in ha)			
	Pomegranate	**Onion**	**Tomato**	**Other**
ISI Certified	24.5	15.31	2.75	1.3
LCDI	0	25.63	11.5	1.1

[1] IAI is an association of all Drip, Sprinkler and other pressurized irrigation system manufacturers in India. It was formed after the dissolution of the erstwhile All India Drip Manufacturers Association" (Dripma) in 1998

Table 8: Farmers evaluation of drip irrigation technologies

Evaluative Criteria	ISI certified Drip Sets	Low Cost Drip Irrigation Sets
Durability	Long lifespan up to 10 years	1-2 Seasons
Performance of set	Even distribution of water, slower rate of discharge	Relatively less even distribution, faster rate of discharge
Cost	Expensive, purchased along with filter, fertigation attachments etc.	Laterals are very cheap, given the relatively short lifespan farmers do not always invest in filters and other paraphernalia
	High investment cost and presence of subsidy requires the investment to be planned	Low cost allows farmers to purchase sets in order to respond to needs as they emerge
Support	Covered Under subsidy scheme. However, farmer must make full payment while purchasing	Not covered under subsidy. Purchased from open market
Uncertainty, Risk & Flexibility	Farmer must be able to tide over the uncertainty associated subsidy disbursement.	Low cost means that farmers who are uncertain of their capacity to use the set are able to lower their exposure to failure.
	Commitment to utilising the set for particular crop for long period, farmer must be able to take advantage of the drip sets durability.	Pepsee sets can be adapted to different crop spacing as all that is required by punching more holes
Crop Choice	Widely spaced Perennial Crops – Pomegranate. Lower cost on account of the lower no. of laterals makes.	More closely spaced Seasonal Vegetables – Onion, Tomato, and Brinjal. Low cost offsets the higher lateral density

Drip irrigation as a planned investment

Seasonal water scarcity in the *Pathar* region had meant that it was not possible to cultivate perennial crops in these regions and confined orchard cultivation to the valley. This changed when in 2006, the government of Maharashtra began promoting farm ponds through a series of schemes, funded by both the central and state government. Farm ponds were originally conceived to help farmers cope with uncertain rainfall by storing run-off for use as life-saving irrigation. In Maharashtra however, farm ponds are used by farmers to capture and store groundwater (Kale, 2017). While the support available under the government scheme is limited to a certain size farm ponds, farmers use their own funds or loans (from banks and relatives) in order to build massive farm ponds. Constructing a farm pond is not cheap, the rocky terrain and shallow soil mean that excavating one requires heavy earthmoving equipment, with the cost of the plastic lining (that prevents seepage losses) being approximately the same as the cost of excavation. A lined farm pond that is 30mX30mX10m can irrigate a 1.5-acre orchard and can cost up to Rs 600,000. Even with farm ponds of this size, water is scarce, and irrigation via drip becomes a necessary part of this assemblage. However, in this context drip irrigation is a relatively smaller component of total investment. The primary advantage that the high-quality ISI sets have over lower cost systems is durability. This makes them the most appropriate for perennial crops, where the drip set are used throughout the year, and farmers are able to take full advantage of their utility and lifespan. For relatively better of farmers, with the capacity to make investments of the size required, the availability of capital is not a major constraining factor, and they can afford to wait for the subsidy to eventually come their way.

Performing drip irrigation

On the other hand, farmers in *Pathar* region who have less secure access to water (but nonetheless have some access) and do not have the resources (land & financial) to invest in farm ponds are unable to grow pomegranate & instead grow seasonal crops like tomato and onion. Farmers here undertake agriculture under conditions for uncertainty. For these farmers decision making closely resembles Richards (1983) notion of agriculture as performance; where decisions are reactive and taken extempore, responding to the monsoon, seasonal water availability, the availability of funds, labour etc.

For these farmers it is in this arena of performance that the decision to invest in drip irrigation is taken. The cost of installing a drip set for a tomato or onion crop is significantly higher than that for a widely spaced pomegranate orchard. As it happens farmers who face the highest upfront costs for drip sets, often have poorer capital endowments. Of the 20 farmers interviewed the average landholding size farmers growing pomegranate and using ISI sets was 4.5 ha, while that for farmers growing tomatoes and onions using LCDI sets was 1.4 ha. LCDI sets allow them to access the efficiency and productivity gains associated with the technology without committing large amounts of capital to it. For seasonal crops, drip sets are likely to remain und-utilised for most of the year and if these are stored properly even LCDI sets can be used for at least 2-3 years, hence farmers growing these crops see durability as less important than their pomegranate growing counterparts. Interestingly, farmers who use ISI-certified drip sets in their pomegranate orchards use LCDI sets for their seasonal tomato and onion crops – explaining that the expenses associated with installing an ISI-certified drip set for onion and other vegetable crops are too high.

Uncertainty plays a role in influencing technological choice in two ways. First, the high initial investment required and the uncertainty associated with the delays in receiving subsidy serves as a barrier. The high costs associated with drip irrigation sets promoted by subsidy have also resulted in a thriving and dynamic market for low cost alternatives. Dealers and those in the agricultural department have pointed out that the demand for these low-cost sets has increased considerably after the change in the subsidy that required the farmer to make the full payment upfront was made. In the study villages the compound annual growth rate (CAGR) between 2012 & 16 for area under ISI sets was 40%, while that of LCDI as 213%, suggesting that the market for low-cost drip systems has developed partly in response to the space opened up by the inefficiencies of the existing scheme (See Figure 7).

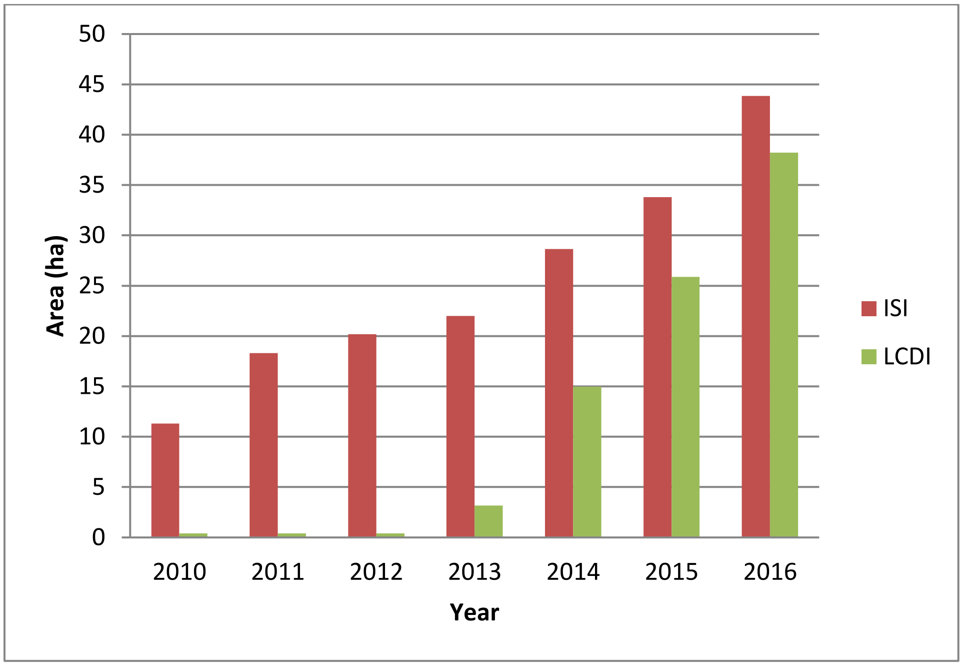

Figure 7: Annual chart of areas under drip irrigation in study villages (Source: Watershed Organisation Trust)

Secondly, these farmers, who lack access to assured irrigation sources & large storage facilities, must also take into consideration uncertainty related to the rainfall. Unlike farmers who have perennial orchards and therefore are committed, as such, to a particular cropping pattern, water-stressed farmers in the *Pathar* region adjust their cropping to take advantage according to the availability of water. Water availability in wells is closely linked to the rainfall in that year, and this in turn influences the area cultivated and no. of crops taken that is monsoon & winter). Farmers also pointed out that given the inter-annual variations in rainfall in the region, it becomes difficult to guarantee that they would be able to use the drip systems every year of these systems life-span reducing the effective return on investment.

5.4. Temporal dynamics: Stepping stone or appropriate technology

Agriculture as performance draws attention to how agricultural decision making is rooted in 'time and place'. In the previous section we explored how the access to water and capital, and crop choice affect adoption. In this section we shall explore how these choices unfold over time, both in the short-term vis-à-vis seasonality & drought, as well as over longer time-scales.

In the short term seasonal changes in the availability of water play a key role in influencing the decision to purchase a drip set, this is particularly true for farmers who grow vegetable crops such as onion and tomato. Bhaskar Phatangare, a farmer in Sarole Pathar explained his decision to use drip irrigation:

> "Last year, we did some work on the well and there was more water. So (this summer) we have taken 10 guntas (0.1 ha) with tomato using drip. In the evening we put the drip on for a half hour. And then when the rain comes it will grow properly."

Tomato prices are extremely volatile and generally high during the summer and fall during the monsoon as supply rises. If he were to plant tomatoes and use the water to irrigate them they would begin to mature with the onset of the monsoon. He would be able to harvest tomatoes crop would be ready early in the season, when prices are high. The amount of water in his well was insufficient for irrigating using conventional flow irrigation, but with a drip set he was able to make the most of the water available. Given that time and resources were limited and this was an experiment, he quickly purchased a low-cost drip set, installed it and planted his crop of tomatoes.

Water availability also influences decisions to invest in drip irrigation. In May 2015 in Sarole Pathar twenty farmers had taken the decision to purchase non-ISI drip sets through, a farmer producer organization, the Mula Valley Farmer Company, which had negotiated a discounted rate for them with the manufacturer and even made an advance payment for the order. However, when the monsoons failed later in the year, the farmers decided to hold off on the purchase as it seemed that in all likelihood there would be too little water to cultivate a crop, even under drip irrigation.

The long-term dynamics of drip adoption and technological choice also raise some important questions. Existing research has posited that LCDI is a stepping stone in the process of technological progress, where farmers experiment with these technologies before investing in higher quality systems (Verma et al 2004, GGGI 2015). Here it is posited that LCDI users, recognizing the gains from using these sets, will re-invest part of their income into enhancing their water control and also help farmers move towards high value crops; where high quality sets are preferred. Some of the farmers interviewed, had in fact shifted to high quality sets after experimenting with non-ISI sets for a few seasons. However, this progression may not fully capture the dynamics of adoption. Limits in the availability of water, both absolute and seasonal, and capital may prevent farmers from diversifying into high value orchards, and instead continue to grow seasonal crops. Importantly, farmers who use ISI systems for their orchard crops continue to use low cost drip sets for their seasonal crops. All this suggests that farmers may prefer to continue using LCDI for seasonal crops. The industry also recognizes the importance of LCDI; while early innovations in this segment were made by small manufactures and NGOs, large manufactures have also entered this segment. This suggests, that it is also important to consider how crop choice, uncertainty and the socio-policy aspects also determine technological choice. At the time of fieldwork, many farmers had only been using LCDI for a few seasons, and more research is needed to track how preferences change over time.

6. Conclusion

Technologies such as drip irrigation present an opportunity to farmers to overcome water scarcity constraints at the farm level. Under an increasingly unreliable rainfall regime, these technologies may present a way for famers to adapt to conditions of water scarcity. Yet as we have shown the pipes and emitters that constitute the material technology of drip irrigation is only a part of a larger socio-technical system, where institutions and processes operating at multiple levels affect how technology is adopted at the local level. This socio-technical system is made up of actors and institutions, ecological and environmental context, and farmer's capacities which together determine the technological choices available and made. By approaching micro-irrigation as a socio-technical system we also show how processes relevant to understanding the dynamics of adoption unfold at multiple scales, while identifying the barriers and enablers to adoption that emerge across scales.

At the farm level we find that a series of factors interact and influence technological choice: costs associated with the sets, the farmers' resource endowment, cropping patterns, and uncertainty. Here we see how these factors interact to influence decision making and technological choice at the farm level. We find that the requirement that the farmer pays the full price for expensive sets available under subsidy scheme, coupled with the delays associated with receiving the subsidy, creates an additional barrier to accessing the subsidy. Interestingly, in the study villages LCDI became popular only after 2012, when the design of the scheme changed. Thus, there is reason to believe that the changes in the subsidy scheme created space for the LCDI market to develop. The uncertainty associated with subsidy disbursement coupled with the uncertainty associated with rainfall and water availability play an important role in influencing the technology that farmers use. This is particularly so in the case of resource poor farmers who grow seasonal crops. Here, low cost drip sets appear to be popular, as these seasonal crops require a higher density of pipes and material on account of the closer row spacing. This coupled with the two forms of uncertainty outlined above makes LCDI more appealing than the high-quality sets promoted through the subsidy scheme.

At the level of policy, the design of the subsidy scheme in Maharashtra has itself created barriers for farmers accessing the subsidy. However simply identifying a barrier is insufficient, identifying why and how and such barriers emerge is important (Shackleton et al, 2015). We have shown that the micro-irrigation subsidy scheme as it has emerged in Maharashtra through a process that involved making trade-offs, between the needs of farmers, manufacturers, implementation agencies and others. This has implications for potential strategies to address this barrier. The experience of other states such as Gujarat and Andhra Pradesh demonstrates that there are multiple ways in which policies can be designed and more research is needed to unpack how these affect not only farmers and those vulnerable to climate change, but also other actors who are part of the socio-technical system. Technological innovations, such as LCDI, that develop from below are able to address and bypass some of the constraints associated with traditional subsidy driven approaches that promote drip irrigation. The emergence of LCDI also demonstrates the limits of subsidy schemes. Including LCDI under the subsidy scheme may be very difficult and possibly counter-productive. As the regulatory environment and quality controls that are concomitant with inclusion under a subsidy scheme may be detrimental to the dynamism that characterizes the low-cost market.

In the context of climate change adaptation, micro-irrigation can be thought of as a no regrets strategy, i.e. the adoption of the technology will lead to positive outcomes regardless of the effects of climate change (Hallegatte, 2009). As a material–technology, the potential of drip irrigation to increase both water-use efficiency and incomes is not in question. However, taking a broader view of micro-irrigation as a socio-technical system draws attention to some of the barriers that users face with respect to adoption and the challenges associated with traditional subsidy driven approaches to promoting drip irrigation. Our findings are relevant to policy research and design, particularly on climate change adaptation. First, they demonstrated how multi-scalar analysis can yield important information on how and why barriers and enabling factors emerge. Further, they show that the intrinsic qualities of promising technical and technological advances are not sufficient for success, we must recognize that that the appropriateness of a given technology is determined by the institutional, socio-economic and environmental context in which it is used. Finally, there is a need for a careful analysis of the institutional setup of programmes that are intended to support adaptation that goes beyond simply identifying barriers and explore how and why these barriers arise and continue to persist. Here it is important to unpack the network of actors and how their interests influence how these institutions evolve. Doing so allows us to develop more complete understandings of the challenges that associated with implementing policy. Further traditional forms of institutional design may not be able to meet the needs of those who are in most need of support and we must explore ways in which we can better design institutional structures and leverage existing ones such as markets, credit to better meet their needs.

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