World Development 140 (2021) 105366

Contents lists available at ScienceDirect

World Development

journal homepage: www.elsevier.com/locate/worlddev

The role of ICT in collective management of public bads: The case of potato late blight in Ethiopia

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ARTICLE INFO

Article history:
Accepted 17 December 2020
Available online 15 January 2021

Keywords:
Collective action
ICT4D
Public bads
Lab-in-the-field experiment
Plant epidemics
Ethiopia

ABSTRACT

What is the role of Information and Communication Technology in the collective management of public bads? We study epidemics of late blight in potato as a collective action challenge in Oromia, Ethiopia. As a highly infectious, air-borne disease, potato late blight represents a public bad: it is non-excludable and non-rival. Managing public bads is a major policy challenge in Ethiopia due to structural inefficiencies and resource constraints to formal interventions. Dispersed rural farmers lack capacity and infrastructure to maintain communication flows that are key for effective collective action. We introduce an experimental, framed, public bads game where randomly selected groups of potato farmers are presented with a collective action dilemma whether to invest in a joint initiative to control late blight (fungicide spraying) or to suffer productivity loss if the threshold is missed. We also manipulate the ICT-mediated communication variable by providing access to a smartphone-based group communicator to a random sub-sample of the participants. We find that collective action problems do occur and participants tend to free-ride on the efforts of others. We show that ICT-mediated communication has a statistically significant positive effect on cooperative behavior, disease control, returns on investment and game winnings. Our qualitative analysis of the voice chats provides evidence that farmers use ICT to: (1) facilitate complex coordination, (2) establish collective norms, (3) detect and pressure 'free riders', and (4) manage reputation to increase trust. This paper complements the existing literature on public bads by studying real-life stakeholders in a real-life collective action challenge. It contributes to the literature on the contested topic of 'ICTrevolution' and its supposed transforming effect on African agriculture. From the point of view of policy, we draw attention to the pivotal importance of improving communication infrastructure in rural regions of Ethiopia, and the opportunities to scale collective action interventions through ICT.

1. Introduction

Collective action problems are collaboration deficits that hinder joint action in the pursuit of a common goal by groups of stakeholders (Hardin, 1982; Olson, 1965). They arise as a result of high individual costs of contribution to the management of the shared resource with uncertain personal benefits and imperfect information (Bodin, 2017; Ostrom, 1990). Collective action problems pose a serious threat to sustainable development (e.g. climate change, contagious diseases, antibacterial resistance, Graham et al., 2019). At the same time, research proves that these problems can be overcome if stakeholders manage to install and maintain peer-to-peer information flows and open communication channels (Nowak et al., 2002; Ostrom, 1998; Smith, 2010; Van de Kragt et al., 1983).

The rapidly increasing availability of information and communication technology (ICT) has sparked optimism about managing collective goods and fostering coordinated action among dissociated populations in rural Africa (Cieslik et al., 2018; Loh, 2015). At the same time, while ICT has already impacted the economic and social connectivity landscapes, its effect cannot be equated with traditional face-to-face communication (Bershadskyy et al., 2019; de Bruijn & Nyamnjoh, 2009; Frohlich & Oppenheimer,

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https://doi.org/10.1016/j.worlddev.2020.105366
0305-750X/

1998). Specifically in the domain of collective action, the extent to which communication medium (face-to-face versus technology-mediated) affects cooperative behavior has been a topic of debate (Bicchieri & Lev-On, 2007; de Bruijn & Nyamnjoh, 2009).

In this research, we use the case study of a potato late blight epidemic in Oromia, Ethiopia, to investigate the potential of ICT-mediated communication to overcome the challenges of collective action. Potato late blight is one of the most serious constraint for Ethiopian potato farmers (Gorfu & Woldegiorgis, 2013). Available fungicides can control late blight but need to be applied in a coordinated manner between neighboring fields to optimize the preventive effect (Pacilly et al., 2016). As a (mainly) air-borne, highly infectious disease, potato late blight represents a public bad: it is non-excludable and non-rival.

We introduce an experimental, framed, threshold public bads game, where groups of potato farmers receive training about potato blight and then face a collective action dilemma: whether to invest in a joint initiative to manage the disease (fungicide spraying) or to suffer productivity loss if the threshold is missed. It is also a lab-in-the-field experiment, as we manipulate the ICT-mediated communication variable: a random subset of our sample received a brief ICT training and access to a smartphone-based communicator for the duration of the three-day long study. The control group was given no opportunity to communicate. Our research questions are as follows:

- Q1. Will a group of stakeholders (potato farmers) reach a collective target (public bad prevention) through individual contributions when everyone suffers if the target is missed?
- Q2. Does ICT-mediated communication influence individual decisions to contribute towards a collective target (public bad prevention)?
- Q3. What are the ICT mediated communication strategies that enable effective collective action?

Our game provides evidence that collective action problems do occur: only 41.7% of our control group managed to reach the threshold number of 'sprayings' to avoid potato late blight epidemics (Q1). We find a statistically significant effect of having access to a smartphone-based communicator (Q2): farmers in the ICT treatment group contribute more to the 'public bad' prevention (+5.5%) and are more likely to reach the threshold (+23.2%). As a result, they have higher returns on investment and higher overall game income. In addition, our demographic data indicate that farmers who are seed producers and those who produce yields beyond household consumption are more likely to exhibit cooperative behavior. Household size was also of significance: farmers from smaller households were acting more cooperatively. We conclude that ICT-mediated communication has an important role to play in the management of public bads, even at very early stages of ICT literacy.

We complement these experimental findings with a content analysis of the smartphone communicator chats (Q3). Drawing on communication theory, we distinguish four strategies through which ICT-mediated communication encourages collective action (Smith, 2010). We find evidence that the farmers use the communicator to: (1) facilitate complex coordination, (2) establish collective norms, (3) detect and pressure 'free riders', and (4) use reputation management to increase trust. These strategies demonstrate the importance of actual communication (peer-to-peer discussion, deliberation and coordination, as opposed to the simple provision of information) in designing agricultural extension interventions.

Our findings provide a theoretical base to assume that the growing popularity of ICT holds considerable promise to attenuate collective action problems that often arise in agro-eco systems (Thapa et al., 2012). A vast majority of extensionist ICT interventions in Africa focus on virtual platforms and data collecting mobile applications that allow for top-down agricultural planning and management (Cieslik et al., 2018; Daum et al., 2018; Mann, 2018). At the same time, a growing literature within development economics investigates the potential of ICT simply as a source of information, in particular on market prices and weather forecast (Aker, 2011; Mittal and Tripathi, 2009). Taking an alternative approach, we study the effect of peer-to-peer mobile phone communication as means of improving information processing, cooperation and coordination efforts of farmers. In so doing, we deepen and extend our understanding of prospect theory and endowment effects (Kahneman & Tversky, 1979; Barberis, 2013; Morewedge & Giblin, 2015, see Sections 2.1 and 2.2) as well as shed light on the link between information provisioning, processing and behavioral change (Section 2.3).

The paper is structured as follows: first, we review the existing literature on ICT4D in relation to agriculture, identifying the existing gaps and controversies. We then present the case study: we provide background information about farmers in Ethiopia and Oromia as a potato growing region and present data on ICT saturation in the country. The 'Methods' section describes our experiment and is followed by results, analysis, discussion and conclusions.

2. Literature review

Collective management of shared resources has recently resurfaced in the well-established domain of public goods theory (Fischer et al., 2014). Following the work of Elinor Ostrom, a number of researchers studied the conditions that allow groups to sustainably manage shared resources (Ostrom et al., 1998; Ostrom, 1999, 2009, see also: Agrawal, 2001; Dietz et al., 2003; Agrawal and Chhatre, 2006).

Challenging Hardin's 'tragedy of the commons', Ostrom argued and proved that communities are able to cooperate without requiring top-down regulation, if certain conditions are met (Ostrom, 1990, 1998, 2008, 2010). Her research identified trust, reciprocity, and communication as three key enabling factors for collective action (Agrawal, 2014; Ostrom, 1998). With reference to the latter, she argued that groups tend to successfully navigate the conflicts between individual/short term and collective/long term interests if their members manage to establish and maintain open communication flows (Ostrom and Walker, 1991; Shankar & Pavitt, 2002, see also: Balliet, 2010).

Importantly, Ostrom's theory and case studies were concerned with the provision of a *positive* resource (e.g. fisheries, clean air). The social institutions she investigated (social norms, peer pressuring, and strategies of conflict resolution) were facilitated by *face-to-face* communication. In our research, we look at the prevention of a *negative* outcome (spread of a contagious disease) facilitated by a *technology-mediated* communication (smartphone-based voice chat).

In the following sub-sections, we review some of the existing literature about public goods/bads, and resulting collective action problems (2.1). We then present some literature concerning the role of communication in experimental, (2.2), and field (2.3) studies, identifying the research gaps that this study seeks to address.

2.1. Public bads, prospect theory and endowment effect

From a theoretical perspective, the decision to prevent a public bad is equivalent to the one of providing a public good of the same utility. At the same time, framing a social dilemma from the perspective of a potential loss as opposed to potential gain does have a noticeable impact on decisions, contrary to rational choice theory. The effect of framing in economic games has been thoroughly examined by the so-called prospect theory (Barberis, 2013; Kahneman & Tversky, 1979; Sonnemans et al., 1998), which explains the effect of framing with the variable of a subjective reference point. Faced with a risky decision potentially leading to losses, individuals are risk-seeking, preferring solutions that lead to a lower expected utility (Alpizar et al., 2011). When applied to our case study, prospect theory would predict the prevalence of cooperative behavior: farmers should contribute to 'spraying' as the relative value of 'losing' is too great (Yesuf & Bluffstone, 2009; Cieslik and D'Aoust, 2018).

Challenges in achieving cooperation in public bad prevention can also be explained in terms of time preferences. In strategically identical games, after repeated iterations, cooperative behavior of players decreases in the case of prevention but stays close to constant in the case of provision (Sonnemans et al., 1998). Research shows that pressed with urgent consumption needs, people are likely to discount the future (Morewedge and Giblin, 2015). Known as the 'endowment effect', irrational short-termism makes people more likely to retain something they already have rather than acquire the same item when they do not yet possess it. In relation to our study, endowment effect would stop the farmers from contributing to the public bad prevention, as the expected gain is both uncertain (conditional on other farmers also contributing) and delayed in time (3 days) compared to withholding cash.

In the light of these theories, our study provides an applied mixed-methods perspective on achieving collective action in an interdependent collective loss dilemma. While literature abounds about the prevalence of high time discounting and endowment effects in real life, usual public bad experiments do not capture them, as they are played within the limited time-frame of one session—typically less than half a day. Furthermore, since experimenters typically use tokens rather than real money—capturing the endowment effect eludes most applied studies. In our study, the participants receive their endowment in cash and take it home to keep as their own, allowing us to mimic the actual free-riding incentives and outside options that people face in real life.

In the case of smallholder households, the relative incapacity to achieve cooperative long-term objectives often results in substantial livelihood losses. In the next section, we discuss the role of communication in overcoming some of the challenges listed above.

2.2. Cheap talk: The role of communication in public goods/bads games and the promise of ICT

Both in the case of public goods/bads games, and in other types of social dilemma situations (e.g. prisoner's dilemma) communication has been found to be the core factor influencing stakeholders' decisions. A recent *meta*-analysis reviewing experimental studies in behavioral economics confirmed a long-standing positive effect of communication on cooperation and collaboration games, with a very large average Cohen's d (d = 1.01)[1] (Balliet, 2010).

To date, different types of communication were studied: face-to-face versus written messages, pre-experiment versus continuous communication, and open versus one-way communication, with invariably positive results (Farrell, 1988; Farrell and Rabin, 1996). A large portion of literature has also looked at the price that the players are willing to pay for being allowed to communicate (Duffy and Feltovich, 2006). The most effective form of communication that helps elicit cooperative behavior is said to be *cheap talk*: information exchange that is unlimited and costless to transmit and receive (Cason et al., 2012; Palfrey et al., 2017). Even though in the case of cheap talk the players are not obliged to abide by their words (i.e. they can lie with impunity), in most cases they do, a mechanism known as self-committing (Blume and Ortmann, 2007; Neidert and Linder, 1990). In response to messages of commitment, other players commit as well, which in turn is known as reciprocity (Duffy & Feltovich, 2006).

What is particularly important from the point of view of our study is that face-to-face communication tends to have a much stronger effect on collaborative behavior than chat or text messages (d = 1.21 and d = 0.46 respectively, Balliet, 2010). This would mean that ICT-mediated communication might not lead to effective collective action. In the next section, we look at the existing applied studies that investigated the role of ICTs in facilitating informed decision-making among farmers.

2.3. From information provisioning to behavioral change – The role of communication

Even though the ICT is believed to boost farmers' decision making capacity by addressing information asymmetries, the empirical evidence is inconsistent. In a seminal paper on Keralan fishermen, Jansen (2007) shows that the adoption of mobile phones by fishermen caused reduction in price dispersion, elimination of waste and a general increase in both consumer and producer welfare. Similarly, in a mixed-method paper studying the mobile phone use in Southwest Nigeria, Ogunniyi and Ojebuyi (2016) describe that mobile phone use increases farmers' income, reduces transaction and transportation costs, and increases farm productivity. Looking at the agricultural value chains, Furuholt and Matotay (2011) argue that improved access to information that mobile phones represent affects the entire cyclic farming life and has resulted in considerable changes in the entire livelihood constructs, increased opportunities and reduced risks for rural farmers. In a study by Salia et al. (2011) the authors find that increased availability of mobile phones increased access to information, improving market efficiencies and reducing price variations across the agricultural value chain. Finally, Mittal and Mehar (2012) findings from India show that mobile phones can act as a catalyst to improving farm productivity and rural incomes.

At the same time, Nakasone et al. (2014) find that while access to mobile phones has generally improved agricultural market performance at the macro level, impacts at the micro level are mixed. Similarly, Tadesse and Bahiigwa (2015) examine the impact of mobile phones on farmers' marketing decisions, finding that that the number of farmers who use mobile phones for price information searching is in fact very small, and those that do, receive higher price only for wheat. Further, an experiment by Fafchamps and Minten on the effect of mobile-based weather and market information in India failed to find significant effects of the price received by farmers, crop value-added, crop losses resulting from rainstorms, or the likelihood of adopting new cultivation practices (Fafchamps & Minten, 2012).

While these controversies all merit further research, it is important to note that the focus of the existing applied studies is on the role of information.(Misaki et al., 2018) Like many other studies within the ICT4D domain, they investigate mobile phones as a source of real-time, low-cost information, be it from agricultural extension organizations (e.g. weather forecast), intermediaries (e.g. market prices) or peers (e.g. new seed varieties). Contrarily, in our study, we look at the role of ICT-based *communication*. While the two functionalities may appear similar (communication does entail information exchange) communication encompasses many additional processes, like discussion, persuasion, and opinion-

[1] Cohen's d is a comparable quantitative measure of the magnitude of the effect of an experiment. It is calculated taking the difference in mean between experimental groups and dividing by the standard deviation. Therefore, a d of 1 means that two groups differ by 1 standard deviation. Cohen's d of 0.8 and above are considered to be 'large' effect sizes; 0.5 is considered 'medium', and 0.2 'small'.

formation, which mediate between information provisioning and actual behavioral change. A number of behavioral theories, like social cognitive theory, or theory of planned behavior, argue that the processes and activities that interactors engage in following the provision of information are more persuasive than the information itself (Leeuwis & Aarts, 2011). Accordingly, ICT-mediated communication may allow new forms of networking and collective organizing (Bennett & Segerberg, 2012). In our study, upon providing the farmers with information about late blight, we allow our treatment groups to jointly process the information, discuss and coordinate the appropriate course of action through the ICT-based communicator. In other words, instead of targeting behaviors directly, we provide a communicative space that enables behavioral change and new forms of collective organizing (Fig. 1). This is in line with viewing ICTs as amplifiers of agricultural extension services, focusing on its communicative rather than information provisioning function.

In the next section, we present the case study under investigation and explain how we conceptualized the potato late blight disease in Oromia as a collective risk, public bad game.

3. Introducing the case study

3.1. Smallholder potato farming in Wolmera/Oromia, Ethiopia

Potato is a key crop in Ethiopia, important for both livelihoods (income source) and food security (high nutritional value, Tadesse et al., 2019). Despite the fact that almost 70% of the arable area in the country is suitable for potato growing, potato yield per unit area has remained low (CSA, 2016; Gebru et al., 2017).

3.2. Potato late blight epidemics (causal agent: *Phytophthora infestans*) as public bad

Among the many biotic constraints that adversely affect potato production in Ethiopia, late blight has been identified as the most important (Damtew et al., 2018; Kassa and Eshetu, 2008). Caused by *Phytophthora infestans*, late blight results in foliage death and tuber rot, which can occur both in the field and while in storage (Pacilly et al., 2016). The pathogen has a short life cycle of less than a week, and produces large quantities of spores. These can quickly spread over large areas, carried by wind and by rain splashes (Zwankhuizen and Zadoks, 2002).

A large part of the Oromia region in Ethiopia is characterized by ideal conditions for late blight occurrence and proliferation: it has high relative humidity, moderate temperature and substantial rainfall (Damtew et al., 2018; Tafesse et al., 2018). The Ministry of Agriculture - recommended containment practices include early planting and mechanical haulm killing (Tafesse et al., 2018). Since the early stages of late blight can easily be missed, the agricultural extension services also recommend preventive fungicide spraying of 3–4 times per growing season.

Farmers play a key role in the control of late blight since they make decisions on crop management, which directly affect its spread (Pacilly et al., 2016, Pacilly et al., 2018). As is the case with all epidemics, constraining late blight is a collective effort: available fungicides can control the disease but need to be applied in a coordinated manner between neighboring fields to optimize their preventive effect. At the same time, farmers would need to make substantial investment in terms of materials (backpack pressure sprayer, fungicide) and labor, while the end-result of spraying remains uncertain. Fields of farmers without effective disease control can act as sources of infection for areas that were sprayed, while large fraction of protected fields can strongly reduce disease incidence in an area, including the unprotected fields (Pacilly et al., 2016). As a result, farmers are facing a classic collective action dilemma: whether to invest in spraying or to free-ride on the efforts of others. The epidemics of potato late blight can be conceptualized as a public bad: as a (mainly) air-borne disease, it affects all potato growers, and having one infected field does not decrease the chances of other fields to also be affected (see Table 1 below).

As discussed in Section 2.2, communication provides an effective way to manage public bads. In the case of potato late blight, improving communication flows between individual farmers could enhance coordination, allowing the owners of the neighboring fields to optimize their spraying efforts. At the same time, establishing and maintaining communication flows is difficult across time (the length of a growing season) and space (vast agricultural landscape). In the next section, we discuss whether the rapid spread of ICT has the potential to address these challenges.

3.3. ICT revolution in Ethiopia

Over the past ten years, mobile phones have spread remarkably rapidly in Ethiopia. The number of mobile subscribers has increased from just 160 thousand to over 50 million between 2004 and 2016(UN ITU, 2020)). The number of internet users grew to over 16 million by 2016 (Fig. 2). As part of this development, some empirical lessons have been drawn from the experiences of different ICT and mobile-based agricultural development focused initiatives such as ATA (Agricultural Transformation Agency) and ECX (Ethiopian Commodity Exchange, Meijerink et al., 2014). According to Minten et al. (2012), almost all rural agricultural wholesale markets in Ethiopia have access to mobile phones. A study by Kaske et al. (2018) in Southern Ethiopia reveals that the majority (90.6%) of phone-owning household heads make phone calls for agricultural purposes, while 85.9% of the household heads receive phone calls related to agriculture.

At the same time, in a randomized experiment on phone use in Ethiopia, Matous et al. (2014) show that farmers typically use the phones to contact their existing social networks as opposed to seeking out external advice. For this reason, contrary to the mainstream extensionist literatures which explore the potential of phones to disseminate expert knowledge to farmers (Damtew et al., 2018), our study focuses on the peer-to-peer communication function.

3.4. Agricultural extension services in Ethiopia

Agricultural extension services in Ethiopia are relatively well developed and have been in operation since 1953 (Berhane et al., 2018). Over the past decade, more than 50 000 new extension agents joined the extension organizations across the country and over 11 000 new farmer training centers (FTCs) have been established (Stellmacher and Kelboro, 2019; Lemma et al., 2011). Despite these efforts, various constraining factor are still limiting extension efficacy (Davis et al., 2010; MoA, 2014). These include limited knowledge and skills of agents, poor infrastructures at FTCs and the logistical difficulty of reaching farmers in remote areas (MoA, 2014).

Even though the public extension system continues to be an important source of information on agricultural technologies and technical practices (MoA, 2014), farmer-to-farmer information sharing and learning is a salient practice. Various empirical studies reported peer-to-peer advice to be the most important source of information for farmers in their agriculture activities (Tafesse et al., 2018; (Brhane, Mammo, & Negusse, 2017); Kelemu, 2017; Egge et al., 2011). A study Matouš et al. (2013) finds that farmers who are socially well connected within the community have less reliance on the extension service as their social networks provides them with opportunities to learn from their peers. In view of the

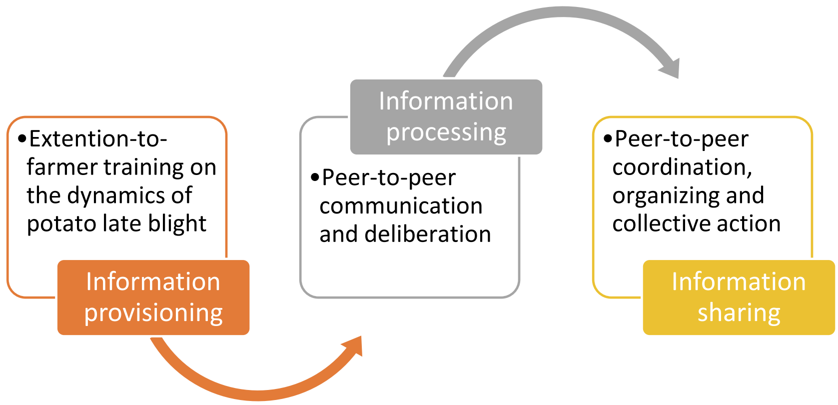

Fig. 1. From information provisioning to collective organizing.

Table 1
Potato late blight as a public bad.

Public bad	Features	Potato late blight characteristic
Non-excludable	No individual can be excluded from its effect	Since potato late blight is (mainly) air-borne, no individual farmer can shield their fields from its spread
Non-rival	Affecting one individual does not reduce the probability of others to also be affected	Non-exhaustible infection rates: spread on one farmer's field does not reduce the probability of spread to other farmers' fields

above, we believe that the ICT may have an important role to play in facilitating potato disease control among Ethiopian farmers by creating communicative spaces where new knowledge can be processed, discussed and assessed, thus amplifying the outreach and efficacy of the extension service.

4. Methods

Our research design represents a mixed-methods approach. First, we employ a game-based framed field experiment. Second, we also set up a qualitative content analysis by recording all of the communications from the group voice chats. The methodology of this study was reviewed and approved by the Social Science Ethic Commission in February 2019.

4.1. Framed field experiment

In order to model the farmers' decision-making process we designed a framed field experiment (Harrison & List, 2004). We chose a participant pool of context-specific stakeholders (potato farmers), topic framing (dry growing season), imposed set of rules (see: 'rules of the game' below) and a field context in the commod-

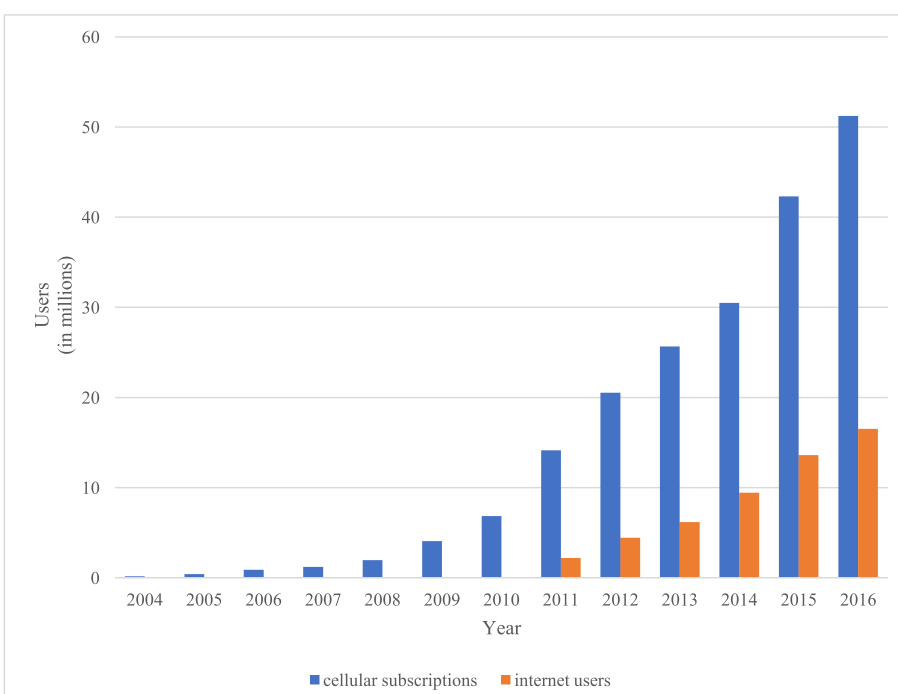

Fig. 2. ICTs in Ethiopia: mobile phones subscriptions and internet users. Source: (UN ITU, 2020)

Table 2
Game income in a successful (left) and unsuccessful (right) game scenario.

Threshold reached/ 'herd immunity'				Threshold not reached/ potato late blight strikes			
Individual farmer's decisions	Remaining funds	Harvest gain	Take-home money	Individual farmer's decisions	Remaining funds	Harvest gain	Take-home money
Sprayed 0 times	600	600	1200	Sprayed 0 times	600	0	600
Sprayed 1 time	500	600	1100	Sprayed 1 time	500	100	600
Sprayed 2 times	400	600	1000	Sprayed 2 times	400	200	600
Sprayed 3 times	300	600	900	Sprayed 3 times	300	300	600
Sprayed 4 times	200	600	800	Sprayed 4 times	200	400	600

ity (playing with real cash money), task (decision whether to spray), stakes (substantial financial incentive) and information set (uniform information on growing conditions).

In cooperation with the International Potato Center in Ethiopia, we conducted seven pretests of our experimental game, teasing out potential pitfalls. The roll-out of the experiment was also preceded by a pilot study with 40 random participants. The four subsections below describe our sampling strategy, the game design, the treatment manipulation and the empirical strategy.

4.2. Sampling strategy

First, we randomly chose eight kebeles in the potato growing region of Walmera. We then randomly drew five villages from each kebele. Using the Ethiopian census lists, we randomly selected seven households from each village (with random replacement) and invited the heads of households to participate in the game.

We divided up the participants into seven groups of five: first arrivals from each village would form group one, second arrivals group two etc. As a result, each group comprised five farmers, each from a different village. This allowed us to control for spill-over effects: even if the participants were to break the confidentiality rule and consult their game decisions with fellow villagers, we would underestimate (rather than overstate) the treatment effects. At the same time, all the farmers playing in each iteration of the game were members of the same kebele, and often participated in joint trainings organized by the FTCs where the game was played, meaning that they were not complete strangers. The farmers' groups were then randomly assigned to either treatment or control groups. In total, we distributed 315 participants from 45 villages into 63 groups: we assigned 135 participants to treatment (27 groups) and 180 to control (36 groups). In order to verify random assignment, all of the participants completed a questionnaire with basic demographic information (see 'Description Statistics' section for more detail).

4.3. Game design

Our game is loosely based on the collective-risk social dilemma game designed by Milinski et al. (2008). At the onset of the game, all of the participants received training about potato late blight. This was to ensure that they all shared an understanding of the contagious character of the disease and understood their interdependency. This information session also represents a generalized 'training' that the FTCs normally organize in each kebele. Following training, we explained the game, with many comprehension checks. Then, our trained assistants conducted individual informed consent sessions with participating farmers. Finally, each participant received a fixed sum of 600 Birr (cash money) which they took home to treat as own.

The game comprised four rounds, played across three days, representing four spraying decisions in the potato growing season. In each round, the participants decided whether to invest in pesticide spraying of their hypothetical potato field. If a player chose to spray, they needed to contribute 100 Birr to the group's common fund (the cost of the pesticide and labor, representing 'public bad prevention'). If the total contributions of the group reached or surpassed 1500 Birr after four rounds of the game (equivalent to everyone deciding to spray 3 times on average), all group members would receive an extra 600 Birr ('successful harvest' reached through herd immunity effect). If the group failed to reach this collective goal, the potato late blight epidemic struck. In such a case, the players' harvest was much diminished, not exceeding the initial 600 Birr .[2]

Each decision was taken anonymously: the participants delivered an envelope that was either empty or contained a 100 Birr bill. The four decisions happened across three days, in the early morning or late afternoon. The players took their decisions in the privacy of their homes, coming to the FTCs only to deliver their envelopes.

Accordingly, each participant faced the same trade-off: the more they invest, the higher the probability that the group reaches the target sum, but the less money remains in their possession of the initial endowment. Our game rules are typical of a classic public goods game: (i) participants have to make individual decisions repeatedly before the outcome is evident; (ii) investments are lost; (iii) everyone's private good ('potato harvest', or final payment) is at stake if the target sum is not collected and the late blight strikes Table 2.

4.4. Control and treatment group manipulation

A random subset of our sample was selected to become our treatment group: these farmers each received a smartphone device with a voice-based group chat application ('ICT treatment')[3]. They were also trained how to care for the device, send and receive voice messages (one-hour long group training). We topped up all the smartphones with data credit so no expenses were borne by the users. Over the course of the experiment (3 days), on-call immediate assistance was provided (we hired field assistants in case of any equipment problems). Farmers with no access to electricity at home could bring the phones to the training center to be charged at no cost at any time. As a result, our control group had no opportunity to communicate, while the treatment group could, if they chose, communicate via the application throughout the 3-day experiment.

[2] Since the take-home sum also represents the compensation for farmers' participation (time spent while playing the game) we did not wish for any of the players to be left with<600 Birr.

[3] We decided to use a voice-based group communicator (as opposed to group chat) because of linguistic differences (Amharic and Oromo speakers); in addition, some of the participating farmers were illiterate.

Table 3
Variables and operationalization.

	Variables	Operationalization	In dataset
Dependent	Collective action (exhibiting cooperative behavior)	Contributions to the collective target	Individual level – number of positive spraying decisions in the game (0,1,2,3,4) Group level – total of all contributions in the game above the threshold level (0,1)
Independent	ICT-mediated communication	Provision of a smartphone device with a group chat function only (voice-based group communicator); representing 'cheap talk'	(0,1)

4.5. Empirical strategy

Table 3 explains the way in which data were operationalized.

We make use of random assignment to the treatment group to test the effect of ICT treatment using a simple OLS specification:[4]

$$y_i = \beta_1 + \beta_2 ICT_i + \beta_3 X'_i + \beta_4 K'_i + \varepsilon_i \quad (1)$$

where y_i is the outcome variable of interest (either investment, reaching the game threshold, return to investment, or a measure of earnings). ICT_i is our treatment dummy, K'_j is a vector of spatial (Kebele) dummies and X'_i a vector of individual characteristics including standard socio-economic variables such as gender (dummy = 1 for male), age and education level (in the form of two dummies, one for finishing primary school and one for secondary school or higher), and household size. These variables are included in any statistical analysis that investigates individual behavior and decisions. We also include two variables that proxy for phone and ICT literacy: owning a mobile phone and owning a smartphone (correlation is only 15% because of a certain degree of substitutability between the two). Finally, we also include control variables that may have affected farmers' familiarity with late blight: land size farmed, whether they produced seed or ware potatoes, and a dummy on whether they were mostly producing for the market (rather than self-consumption). Even though the randomization into treatment should ensure that all these control variables are balanced across treatment and control groups, we still include them in the analysis to be able to tease out any potential confounding effect. In the results table we also present a test of difference in coefficient (Durbin-Wu-Hausman Chi^2) with respect to a naive specification that does not include any control variables. We also report a test of joint significance for each specified model, and a Variance Inflation Factor (VIF) to test for potential multicollinearity and endogeneity across independent variables. ε_i is the error term which we cluster at the group level.

4.6. Qualitative data collection

Qualitative data were gathered parallel to the implementation of the game. We recorded all the voice messages exchanged between the farmers in the ICT treatment group over the three-day long experiment.[5] These were subsequently downloaded, transcribed and translated to English. All the qualitative data were coded and analyzed.

5. Results

5.1. Descriptive statistics and sample characteristics

Table 4 presents the key descriptive statistics for the treatment and control groups, respectively. The sample is balanced in all the variables—a sign that our randomization was successful. Our participants were for the vast majority males (93%), about two thirds of them had at least primary education, with a further 17% having continued to secondary school or above. On average, the farmers in our sample were 39 years of age (ranging from 17 to 84), and belonged to a household of 5 persons. They all farmed land (0.5 ha on average, of which we take the natural logarithm for ease of interpretation), and many of them sold at least some of their potato yield as seed for other farmers (73%). Market penetration was quite high: 78% of our sample produced primarily for the market, rather than exclusively for household consumption. About 84% owned at least a simple mobile phone, and 11% owned a smartphone.

5.2. Experiment results: Does access to ICT facilitate collective action?

Our results indicate that collective action problems do occur: only 41.7% of our control group managed to reach the threshold number of 'sprayings' to avoid potato late blight epidemics (achieve 'herd immunity'). This provides an important indication that the game design and scenario represent an accurate model of the real-life situation, where many farmers indeed refrain from spraying, either at times or altogether.

Second, we looked graphically at the game results over four decision-taking rounds to understand how having access to the anonymous group voice messaging changed the way in which farmers approach the public bad. Fig. 3 shows the percentages of players that decided to invest 100 Birr of their initial endowment to 'spray' their fields in each of the four subsequent rounds. In round 1, over 90% of farmers decided to invest in preventing the public bad. This dropped to just below 85% in round 2, implying that 15% of farmers opted to free-ride. Up to this point, we observe almost no difference between the decisions in treatment and control groups. However, by round 3, we observe statistically significantly more free-riders in the control group (blue line) than in the treatment group (red line). Those with access to ICT-based communicator free-rode in 31.9% of cases, against 43.3% of cases in the control group. It is interesting to note that this difference in collective action capacity happens exactly at the third round, when the final outcome of the game could still be swayed. Expectedly, by round 4 the difference between the two groups is again null as many groups may already reached the threshold or were in no position to reach it anymore. Moreover, Fig. 3 clearly shows how both groups decrease spraying frequency across the rounds. This is in line with the existing literature, where free-riding behavior tends to increase with time. However, the drop in the control group is much sharper for round 3, indicating that many players decided to free-ride before the threshold could have been reached.

How did these differences affect the likelihood of groups to reach the 'herd immunity' threshold? Table 5 presents the results of a regression analysis over three dependent variables. All three columns also control for individual characteristics and for kebele

[4] One important exception to using OLS is when we study players' investments across the four rounds. In this case and only in this case we treat the sample as a panel with four investment decisions and use a random effects specification. A fixed effects specification is not possible because both treatment and all the control variables are time-invariant.

[5] Farmers were informed about the conversations being recorded and agreed to it during the informed consent procedure (with translators/facilitators).

Table 4
Descriptive characteristics of control and treatment groups.

Variables	Control group Observations	Control group Mean	Treatment group Observations	Treatment group Mean	Mean Difference
Male dummy	180	0.917	135	0.963	−0.046
Primary education completed	180	0.606	135	0.644	−0.039
Secondary education or above	180	0.200	135	0.133	0.067
Age in years	180	38.50	135	38.57	−0.07
Household size	180	5.383	135	5.259	0.124
Land farmed (ln ha)	180	0.572	135	0.606	−0.033
Seed production	180	0.694	135	0.785	−0.091
Mostly sells to market	180	0.756	135	0.807	−0.052
Mobile phone ownership	180	0.839	135	0.837	0.002
Smartphone ownership	180	0.106	135	0.111	−0.006

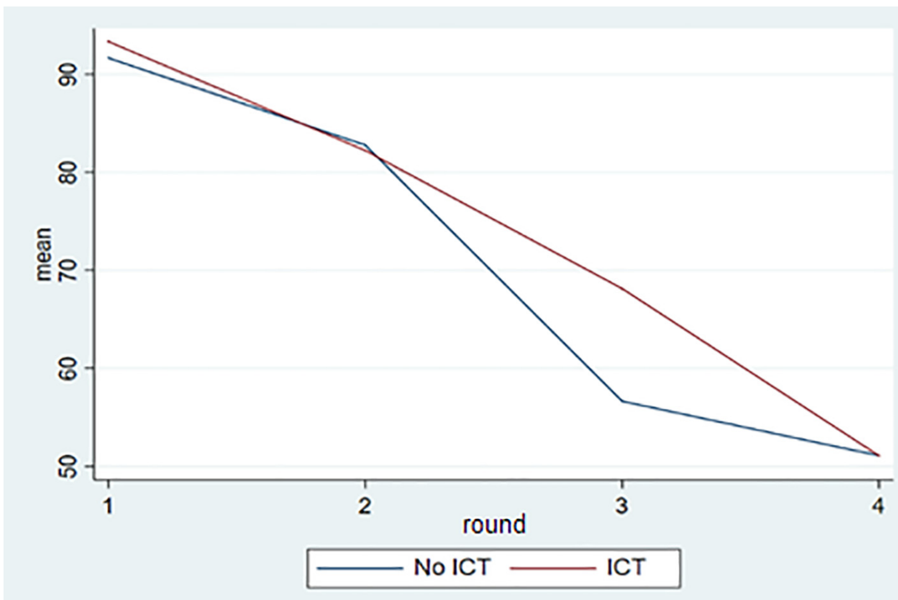

Fig. 3. Percentage contributors to public bad prevention, per decision (1–4 round), by group.

dummies. Standard errors are conservatively clustered at the group level.[6] Column 1 shows that the difference in free-riding for round 3, between treatment and control groups is statistically significant at the 5% level, with an increase in investment of 11.16 from the base of 56.67 Birr per person, or 19.7%. Column 2 shows that this difference is maintained, although lower, when we look at average investments over the four rounds: in this case the increase in investments to prevent the public bad is of around 5.2% and still significant at p = 0.05. Finally, column 3 looks at the likelihood that the immunity threshold is reached: the groups with ICT access have 24 percentage points higher likelihood of reaching the goal. Given a control group standard deviation of 0.49, this is equivalent to a Cohen's d of 0.49—a medium sized effect in line with the average effect sizes for chat and text message communication experiments (Balliet, 2010). While R-squared measures are in line with similar studies (and above 62% for column 3), all other explanatory variables do not enter significantly, with the exception of round effects and kebele dummies (which also capture local characteristics) and a marginally higher likelihood to reach the threshold for those who sell to market rather than home-consume potatoes. This said, a test of joint significance of independent variables (F-test or Wald Chi^2 test) is significant in all three columns. Also, the variance inflation factor (VIF) is safely below the threshold of 5, revealing the absence of multicollinearity across controls. Finally, a Durbin-Wu-Hausman (DWH) test comparing the regressions shown in the table with their respective naive (without controls) reveals that the ICT coefficient is not significantly biased by the presences of controls (p-values always insignificant).

As illustrated by the above analysis, the farmers assigned to the ICT treatment group were more likely to contribute to collective public bad prevention (individual level) and more successful in reaching the immunity threshold (group level). Table 6 explores how this reflected on their Returns to Investment (ROI), on their absolute game earnings (in Birr) and their relative game earnings compared to the control group. Column 1 shows that for every 100 Birr invested, ICT-enabled participants had returns to invest-

[6] We test for the normality and heteroscedasticity of residuals in the OLS specifications. First, we use the Hamilton Interquartile Range Test (iqr command in Stata) to test for normality and symmetry of distribution of residuals, and find no severe outliers in either investments (residuals mean= −1.2e^-07; std.dev.= 44.86) or threshold reached (residuals mean =4.5e^-10, std.dev.= 0.306). Next, we test for heteroscedasticity using Breusch-Pagan Cook-Weisberg tests (estat hettest command in Stata), which fail to reject the null of homoscedasticity at the 5% significance level (chi2(1) = 3.56 (p=0.0591) and chi2(1) = 1.17 (p=0.2785) respectively). Nonetheless, since we have reasons to assume mild heteroscedasticity and clustering, here and below we always adjust and present standard errors with a heteroskedastic-robust standard error correction, clustering them at the group level. This will not affect the unbiased estimation of regression coefficients, but provides a slightly more stringent test of significance (due to the ensuing higher standard errors).

Table 5
Spraying investments and disease control threshold reached.

	Investment round 3 (Birr)	Investment average (Birr)	Threshold reached (%)
Control group mean	56.67	70.56	41.67
ICT	11.16	3.70	0.24
	(5.003)**	(1.865)**	(0.078)***
Male dummy	10.13	0.89	0.08
	(9.468)	(3.211)	(0.089)
Primary education competed	−0.28	−0.79	−0.01
	(7.288)	(2.829)	(0.037)
Secondary education or higher	2.42	0.26	0.02
	(8.160)	(3.967)	(0.047)
Age in years	−0.16	−0.02	−0.00
	(0.328)	(0.133)	(0.002)
Household size	1.14	0.73	−0.01
	(1.477)	(0.591)	(0.010)
Land farmed (log of ha)	−1.03	−0.21	0.00
	(4.032)	(1.644)	(0.021)
Seed production	1.58	−3.37	0.05
	(6.878)	(2.586)	(0.038)
Mostly sells to market	1.24	−2.12	0.08
	(8.303)	(2.961)	(0.046)*
Mobile phone ownership	−2.99	3.87	0.09
	(7.365)	(3.070)	(0.054)
Smartphone ownership	0.43	−3.59	−0.06
	(10.345)	(4.922)	(0.053)
Round		−14.48	
		(1.202)***	
Kebele dummies	Yes	Yes	Yes
Observations	315	315 × 4	315
R-squared	0.152	0.175	0.626
Tests of joint significance of all variables in model	F(19, 62) = 5.82***	$Chi^2(20) = 337.13$***	F(19, 62) = 33.25***
DWH test of coefficient difference vs. naive (without control variables)	Chi^2 (1) = 0.07 p-value = 0.7972	Chi^2 (1) = 0.36 p-value = 0.5509	Chi^2 (1) = 0.08 p-value = 0.7756
Multicollinearity test (mean VIF)	1.74	4.60	1.74

Cluster robust standard errors at the group level in parentheses (63). *** p < 0.01, ** p < 0.05, * p < 0.1.

ment that were 30 Birr higher than their counterparts. As a result, on average they earned almost 70 Birr more at the end of the experiment (column 2), which is 10% more than the control group in relative terms (column 3). Besides kebele dummies, we find that those selling potato seeds have slightly higher income at the end, while participants with larger households seem less fortunate in terms of game gain.

Interestingly, we also find a negative coefficient of smartphone ownership in column 1. We can conclude that the ICT technology allowed higher returns in the game across the board, even for those at very early stages of ICT-literacy (Table 6). Once again, the DWH test for equality of coefficients, the F-test of joint significance and the VIF are well behaved in all three columns. The R-squared are subdued, especially for ROI as low as 11%. This is to be expected, given how ROI are largely dependent on other people's decisions in the game: even the most cooperative player may not see their earnings and ROI increase if the rest of their team plays uncooperatively.

Table 6
Returns to disease prevention investments and game earnings.

	Returns on Investments (Birr)	Absolute earnings (Birr)	Relative earnings (%)
ICT	0.30	67.72	0.10
	(0.074)***	(14.262)***	(0.022)***
Male dummy	−0.05	−0.82	−0.00
	(0.122)	(20.990)	(0.032)
Primary education competed	0.00	5.82	0.01
	(0.144)	(13.276)	(0.020)
Secondary education or higher	0.02	−16.56	−0.03
	(0.137)	(18.857)	(0.029)
Age in years	−0.00	−0.85	−0.00
	(0.006)	(0.814)	(0.001)
Household size	−0.03	−7.16	−0.01
	(0.024)	(3.541)**	(0.005)**
Land farmed (ln of ha)	−0.03	−1.91	−0.00
	(0.070)	(8.841)	(0.013)
Seed production	0.09	21.63	0.03
	(0.095)	(12.852)*	(0.019)*
Mostly sells to market	−0.01	−16.05	−0.02
	(0.105)	(16.690)	(0.025)
Mobile phone ownership	−0.02	22.05	0.03
	(0.117)	(16.022)	(0.024)
Smartphone ownership	−0.28	−21.88	−0.03
	(0.140)*	(18.759)	(0.028)
Kebele dummies	Yes	Yes	Yes
Observations	315	315	315
R-squared	0.117	0.384	0.384
Tests of joint significance of all variables in model	F(19, 62) = 5.57***	F(19, 62) = 17.51***	F(19, 62) = 17.51***
DWH test of difference in coefficients vs. naive (without control variables)	Chi^2 (9) = 0.99 p-value = 0.3196	Chi^2 (9) = 0.17 p-value = 0.6779	Chi^2 (9) = 0.17 p-value = 0.6779
Multicollinearity test (mean VIF)	1.74	1.74	1.74

Cluster robust standard errors at the group level in parentheses (63). *** p < 0.01, ** p < 0.05, * p < 0.1.

5.3. Qualitative results: How does cheap talk work?

Having access to all the voice messages sent across the experiment provided us with a wealth of qualitative data. Apart from content relevant from the point of view of the game, a number of recorded messages reveal extended social conversations. Some of the farmers discussed other agricultural topics, unrelated to the game (e.g. crop failures, like bacterial wilt, crop prices) as well as local news. For example, one of the farmers record repeated messages to his group members, asking them to come over and help him harvest his teff before the storm: '*Please, people of (name of village), the rain has fallen on two piles of teff on my field! What do you think about this? Now, I have no time to think about potato, rather, all I am thinking of is my teff, which is suffering out there from rainfall. So I need your help!'*. This and other communications illustrate how quickly the farmers learnt to use the phones for purposes that they prioritized.

The content analysis of the messages allowed us to observe how new information about the late blight dynamics is processed and discussed by the groups. In addition, analyze and categorize the ways in which our players use ICT-mediated communication to achieve collective action. We find evidence that the farmers use the voice communicator to: (i) facilitate complex coordination, (ii) establish collective norms, (iii) detect and pressure 'free riders' and (iii) use reputation management to increase trust (Smith, 2010).

5.4. Processing the new information about the late blight dynamics

A number of recorded messages are illustrative of processing the information received at the training about late blight. One of the participants opened up the group chat discussion by saying: '*Today, we saw an interesting and impressing thing! (...) For example, let us say there are ten hectares of potato fields in the same area. Out of the ten hectares, if eight of them were sprayed and the rest two fields lack spraying, the fields that were sprayed may help in reducing late blight from the neighboring fields that were never sprayed. Therefore, we learned as if it is possible to be benefited at the expense of others in managing potato late blight.*' Other farmers repeated the key 'lessons' from the training, as if to ensure that all the other group members understood it too: *'Our discussion was about spraying chemical to control potato late blight disease. Spraying four times and more has no value, you hear me? Spraying twice or three times is good, but not spraying at all has negative effect and our potato might be damaged.'*

At the same time, even though the framing was as detailed and specific as possible, the chat messages reveal that at times, the farmers found room to interpret the game conditions in their own way. This, at times, was at odds with their previous beliefs and experience. As expressed by one of the participants: *'As we learned yesterday, the plan for managing potato late blight is contributing 1500 and more. But, from the point of our experience, spraying only makes sense to the maximum of two times, do you not agree? If we contribute based on this experience, we are going to contribute only 1000, which is below what they said we need for controlling the disease. In another way, if each of us keeps 200 birr in our pocket, we might be defeated by the other groups. So, what shall we do?* Another farmer pointed to the alternative late blight prevention methods, not captured by our game scenario: *'We have to plough our potato field again and again and then we should spray just a little bit of the late blight chemical, once in two weeks, so as to get good production. That is what I do.'*

As illustrated by these fragments, following the information provision, farmers engage in lengthy discussions about the relevance and accuracy of the spraying, seek alternative, lower-cost solutions, compare and contrast strategies and exchange value judgements. This offers an interesting insight from the point of view of future interventions: instead of recommending a single course of action, FTCs should engage the farmers in a discursive exchange where competing views are discussed. This is consistent with the existing literature on the efficacy of agricultural extension services (Pacilly et al., 2016; Tafesse et al., 2018).

5.5. Facilitating complex coordination

Arguably the most important functionality of the chat was facilitating coordination between players: by thinking up a strategy and trying to figure out the round's totals, the farmers use common sense and clear logic as they lay out plans for action: *'We have to think carefully about what we are going to contribute in our tomorrow morning session. Because the game requires critical thinking, it does'* - warns one of the players. Another one explains more directly: *'my group members, we have contributed 1500 birr. So, do not contribute hereafter. Because contributing more than 1500 is meaningless. Therefore, put an empty envelop in the ballot.'* Taking stock, summing up contributions and drawing plans for action is prevalent in most communications: We *'have learned a lot from the training. It is difficult for me to quantify the knowledge we acquired and many thanks to our government for doing this for us! My group, we have contributed only 400 birr in today's session... But I ask you, now, my group, we must improve our contribution by tomorrow.'* Warning his group not to overpay, another farmer explains: *'My dear group members, we have contributed the expected amount for spraying. Therefore, we are not expected to contribute more since contributing more than the required amount for spraying has no value rather than exposing us to extra expenditure.'*

Unfortunately, this also includes unsuccessful attempts: despite the fact that three sprayings per person was the 'winning' strategy, one of the farmers addressed his group members in the following way: *'we know spraying two times is our responsibility. Yesterday, we contributed 500 and today, we contributed 500. We also know from experience that spraying potato more than twice is a problem; and leads us to extra expenditure. Hereafter, we have to keep two hundred birr in our pockets. That much is enough for spraying. Therefore, we all, my group members, we should put an empty envelop in this ballot now.'* As it happens, the other members did not question the strategy, and the group did not achieve a successful harvest. This quote offers a good example of the potential threats that increased communication brings to collective action efforts: apart from spreading information that is useful, correct and helps improve coordination it also facilitates sharing of misguided advice, false beliefs and erroneous agricultural practices.

To sum up, in accordance with related literature, we find that communication may improve coordination by reducing inefficiency that comes from wasteful under – contribution as well as over – contribution (Blume & Ortmann, 2007; Marini et al., 2018; Palfrey et al., 2017).

5.6. Establishing collective norms

'Since discussing together is better than working alone, let's always discuss together' advises one of the farmers, introducing open and continuous dialogue as a collective norm for his group. Calling for more communication from all group members ('*Why I don't hear you say anything. We must discuss! We have the advantage of having this device to discuss together!*'), is a frequent strategy: in many instances, the farmers express their willingness to listen to everybody, and decide democratically. Another participant called out: *'Hello, hello, why did you switch off your mobiles? Is this the objective? Why don't we discuss together? We are expected to discuss potato, and late blight. Again, it is good if we discuss and agree on how much birr we should contribute and the amount of birr we should keep in our pockets. So please, don't keep silent and let's discuss.'* Calling on the code of ethics, some farmers also present contributing to spraying as one's responsibility to the group. *'My group members, please understand that: yesterday we contributed very little. It is possible to say, well, it was actually zero participation. Therefore, today all of us have to participate so as to win this game! (...) Therefore, we all should participate more, in order to compensate for our yesterday's insufficient participation so that we can win this game.'* By calling for contributions in the name of a collective win, the farmers establish peer-solidarity as a rule that will allow them to maximize their profits. In line with this, we also observe frequent call-outs to 'outdo' the other groups such as: *'For my group members; what I want to inform you is that this game looks like an exam in a class! We have to be competent and be the first! This, by contributing not <1500 birr based on the good lessons we acquired from the training.'* Deciding that all members must commit to communicating and stressing peer solidarity represent an effort to instate at least rudimentary 'norms' to govern the group's actions. Considering the relatively short time of the game and the added difficulty of navigating the new medium of communication, they constitute an impressive attempt of bottom-up organizing.

5.7. Detecting and pressuring free-riders

'Guys, listen, there is a person who cheated us 100 birr; am I right? Who is he? Why did you withhold it?' Our game did not have a punitive element: the group participants could neither detect nor pun-

ish the free-riders. This, however, does not prevent the participants from trying: the voice chats are full of calls to free-riders to expose themselves, and to change their malignant ways: *'Listen, don't keep the money in your pocket. The money is not yours. Now, contribute again and again to win the game'.*

The only way in which the groups can detect free-riders is to communicate about the amounts contributed. Those of the participants who are not active in the chat are often singled out as potential 'cheaters'. Having observed free-riding, one of the farmers pronounces: *'Now, we have identified each other except one guy. We are five in number. If each of us contributes 300 birr, it would be 1500 birr. But, the guy, the one whom we didn't get yet, is cheating us by keeping the money in his pocket! If we get the chance to know him, we will advise him so as to contribute money.'*

For other groups, pleading and appealing to the members' good sense is the only pressuring option. One of the farmers recorded the following message: *'Even though we don't know each other, let's contribute for spraying, together. Don't save the money for drinking "Tej"*[7]*. Let's try to be the winner by improving what we lost today for tomorrow!'* Another one proclaimed: *'Now, our result has reached 1300 birr. By tomorrow, we should contribute more even up to 1800 birr. Those of you who are sending an empty envelop by keeping the money in your pocket have to stop such activity!'*

Importantly, in most of the groups only a couple of members would communicate continuously throughout the three day-long experiment, while one or two would remain inactive in the chat. At the same time, observational data from our IT assistants suggest that even the 'silent' farmers listened to all the messages. By choosing to be passive participants in the communication process they could choose not to self-commit (and not to contribute) while monitoring the commitments (and contributions) of others.

5.8. Reputation management

Appealing to the sense of virtue and good name to elicit generous contributions was another attempt to elicit contributions from other group members. One of the recorded messages states: *'For all participants of (name) kebele; please put the money given to you in an envelope and submit, submit! (...). Don't be anti-development by not contributing the money and let's live for our name.'* Another farmer warns: '*All participants, good morning. Tomorrow we finish this whole thing at 3:00 pm. So we have to finish in a good manner! If we finish with below the minimum requirement, it's possible to say we couldn't manage the disease (...) and we walk away carrying the disease only in our hands!'* To some, over-contributing to spraying is the 'right thing to do' and takes priority over maximizing their game winnings: '*We know that the disease can be transmitted from somebody else's field to the others. There are also some individuals in dilemma, which means some farmers are thinking about the advantage they may get from farmers spraying their potato field which is close to their potato fields. But this is not acceptable! So every farmer has to spray at least four times. We should not worry about the money we are going to contribute. Again, I tell you that never agree with the idea that contributing more than 1500 birr has no value. We have to contribute even up to 2000 birr!'*

Other 'reputation management' strategies include elaborate invocations that signal good education (*First of all I would like to thank our extension workers for their commitment in selecting our kebele for such kind of training! It's well known that potato has been improving our lives, so it has!*), displays of agricultural knowledge (*'Late blight is caused by bacteria and fungus. These bacteria and fungus can be transmitted from somebody's plot/field to the others by wind. Generally, the training that we took yesterday was very impressive and helpful in managing the late blight disease);* as well as ornate thanksgiving as signs of good education, manners and competence (*So I would like to say many thanks to those who gave us the training (...). We, who are here, are so lucky in getting this chance and we need to say many thanks to the organization by representing our community!).* In some cases, religious invocations were also present: *This chance is given us by God. So what, our group members, we discuss the potato late blight?*

While in most contexts studied by Ostrom and others, the group members are close neighbors and belong to one community, in our game farmers know nothing about the composition of their respective groups. For this reason, reputation management is an important strategy to induce trust among their peers, which in turn triggers reciprocal contributions and allows the group to avoid collective loss.

To sum up, we find evidence of four communication strategies, made possible through the communicative function of the ICT. When face-to-face communication is restricted (i.e. when geographic dispersion makes it both costly and time-consuming), ICT enables everyday communicative exchanges and self-organization among farmers, amplifying the effect of the training.

6. Discussion

This study provides evidence that collective action is difficult to achieve for farmers battling potato diseases in Ethiopia: only 41.7% of our control group managed to reach the threshold number of 'sprayings' to avoid potato late blight epidemics (achieve 'herd immunity' effect). This is despite the fact that all farmers received training that explained the contagious character of late blight, proving that simply providing relevant information is not enough. We also find that having access to a smartphone-based communicator does matter: farmers in the ICT treatment group contribute more to the 'public bad' prevention and are more likely to reach the threshold. Being able to process the new information with peers through an open ICT platform triggered behavioral change and allowed the farmers to better assimilate new information and coordinate their disease control efforts.

Our qualitative analysis revealed that the strategies employed in ICT-mediated communication were very much alike the ones observed in existing face-to-face studies. The observed communicative strategies (coordination, establishing collective norms, detecting free riding, managing reputation) appear to be linked to the social institutions that Ostrom identified as conducive to collective action. Against this background, the paper makes three important contributions:

First, we provide quantifiable evidence that improving the communication capacity of groups increases the individual members' likelihood to contribute to a collective target. While this is in line with the existing studies (Farrell, 1988; Farrell & Rabin, 1996), we model the individual choices not only to realize a collective gain but also to avoid a collective loss ('public bad', Sonnemans et al., 1998; Milinski et al., 2008; Costello et al., 2017; Cardenas and Carpenter, 2008). As such, our research contributes to the understanding of risk perception, as well as choices over short term/ long term gain/loss (prospect theory and endowment effect). Our results may guide a wide array of agricultural interventions, ranging from pest control to organic farming (Reeves et al., 2017; Costello et al., 2017). Our study makes clear that public bad problems (like plant diseases) pose collective action challenges and require interventions aimed at supporting collective responses (Graham et al., 2019). This contrasts with existingagricultural extension approaches which are frequently geared to supporting individual decision-making (Van Der Waals et al., 2003).

[7] 'Tej' is an alcoholic beverage frequently consumed in Oromia.

Second, we contribute to the existing body of research on the role of technology in threshold public bad games by introducing ICT-mediated communication (Bicchieri & Lev-On, 2007; Lupia & Sin, 2003). The existing studies only looked at ICTs as a source of information (from peers or from institutions). Our experiment provides a first applied quantitative perspective on the contested topic of 'ICT-revolution' and its supposed transforming effect on African agriculture by looking at ICT as a platform for communication, and not just information source (Aker, 2011; Etzo & Collender, 2010; Issahaku et al., 2018).

Third, our game represents a methodological innovation in the lab-in-the-field domain (Cardenas and Carpenter, 2008; Voors et al., 2012). As opposed to to the existing approaches whereby players gather on location and take their game decisions on the spot, our game is played over the period of three days and decisions are taken at home. In addition, the vast majority of serious games with monetary payoff is played with points, tokens or fake bills. The farmers participating in our experiment play with real Ethiopian Birr. This introduces a novel degree of realism in the experiment, as participants wanting to engage in cooperative behavior had to part with real money: an endowment they had received upon registering and taken home as their own. While experiments with carefully controlled conditions prevail the literature on public goods/bads games, we believe it is important to explore how individuals' preferences in real-life settings, such as this one, shape behavior.

6.1. Revisiting the ICT debate

Despite the promising results of the study, it is crucial to point out that, especially in international development, new technologies often generate optimism beyond their scope (Kuriyan et al., 2008). As science and technology studies scholars have long pointed out, new technologies are only amplifiers, and not substitutes of, human capacities (Andersson et al., 2012; Toyama, 2011). While having access to ICT significantly improved the disease control capacity of our farmers, having prior understanding of the interdependency enforced by the disease dynamics was a precondition for effective collective action. Similarly, our findings on 'fake news' reiterate that ICTs may have positive impacts on people's lives and livelihoods only to the extent that people are willing and able to use it responsibly (Toyama, 2011).

6.2. Limitations of the study

Our study has some limitations that need not be neglected.

First, our game focusses on 'cheap talk': farmers in the treatment group are provided with pre-set smartphones that are fully charged and loaded phone credit. While the prices of ICT hardware and subscription plans in Ethiopia are decreasing, the combined cost of communicating through a smartphone is still substantial from the point of view of a potato farmer. We refrained from charging the farmers to encourage their use of unfamiliar technology.

Second, we experienced some difficulties in the field: since the vast majority of our farmers never owned smartphones, some had trouble navigating their devices. We had a couple of cases where the communicator was uninstalled, or passwords were set, incidentally, by unknowing users. These we resolved on the spot by our IT assistant). In any case, even when observed, the cases of ICT misuse resulted in us understating, and not overstating, the results.

Third, our experimental game was geared towards the impact of ICT-mediated communication alone, while in real life farmers also meet and talk face-to-face. In our game, they were randomly placed in groups of five and had limited prior knowledge of their co-members as they came from five different villages. Our choice of experimental design was necessary to minimize personal bias and to study the potential of innovative transaction cost cutting technologies. Future studies should aim to capture, compare and contrast the effect of both types of communication strategies considering their respective transaction and information flow costs.

7. Conclusions

Contrary to the mainstream literature that focusses on ICT as an information dissemination tool (Avgerou, 2008; Walsham, 2017), our study focused on the peer-to-peer communication function. We show that open social arrangements, enabled by ICT, can help to catalyze the development impacts (e.g. of extension services). Our findings demonstrate that ICT systems fuel both: amplification (ICT allowing for discussion, processing and assimilating new information) and transformation (ICT as enabling more efficient coordination) of social activities that can be powerful drivers of development (Smith & Elder, 2010). In so doing, we also contribute to the emergent literature on collective organizing (Ostrom, 2010).

While ICT alone will certainly not solve the issue of potato late blight in Ethiopia, the case does allow us to draw some important lessons to guide future interventions. While traditional economic models tended to recommend either government or market regulation in dealing with shared resources (both goods and bads), we show that technology-mediated communication may facilitate efficient collective action. For this to be effective, however, regulatory approaches to public bad preventions should be coordinated with community consultations about the preferred ways to manage natural resource problems.

While our findings are in line with Ostrom's theory in relation to the role of communication in facilitating collective action, more research is needed to investigate the potential of ICT in advancing social trust and reciprocal relations. Both of these were Ostrom also identified as indispensable for effective management of shared resources (Ostrom, 1998).

Translating technological advances into tangible economic benefits has always been challenging in smallholder agriculture (Etzo & Collender, 2010; Tadesse & Bahiigwa, 2015). Contrary to apps and virtual platforms that require both investment and maintenance, increased connectivity is an inevitable consequence of the rapidly spreading ICT networks. Harnessing its potential for facilitating collective action could bring us closer to transforming smallholder farming in Africa, improving livelihoods, and achieving Sustainable Development Goal 2.

Acknowledgements

This paper was realized within the interdisciplinary research consortium: Responsible Life-Science Innovations for Development in the Digital Age: Environmental Virtual Observatories for Connective Action (EVOCA). The authors are thankful for the financial support of the Wageningen University Interdisciplinary Research and Education Fund (INREF) and Forum for Agricultural Research in Africa (FARA).

The fieldwork for this paper was made possible thanks to the collaboration between Wageningen University and International Potato Center-Ethiopia (CIP-CGIAR). The authors are also indebted to the agricultural extension officers in Oromia, Ethiopia, who made the data collection possible by sharing their insights and facilitating the cooperation with the local communities.

This research would not have been possible without the assistance of the local facilitators: Adeba Tilahun Daba, Birhanu Tadesse Goshu and Hamsalu Dereje Shiferaw, to whom the authors extend their warmest gratitude. Last but not least, we would like to thank all the farmers who played our game for their active participation and for allowing us to gain insight into their lives.

CRediT authorship contribution statement

Katarzyna Cieslik: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing - review & editing, Writing - review & editing. **Francesco Cecchi:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Supervision, Validation, Visualization, Writing - review & editing, Writing - review & editing. **Elias Assefa Damtew:** Conceptualization, Investigation, Data curation, Writing - review & editing. **Shiferaw Tafesse:** Conceptualization, Investigation, Data curation, Writing - review & editing. **Paul C. Struik:** Conceptualization, Investigation, Data curation, Writing - review & editing. **Berga Lemaga:** Conceptualization, Funding acquisition, Project administration, Resources, Supervision, Writing - review & editing. **Cees Leeuwis:** Conceptualization, Funding acquisition, Project administration, Resources, Supervision, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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