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Trusted sorghum: simulating interactions in the sorghum value chain in Kenya using games and agent-based modelling

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ABSTRACT

Development programmes are increasingly supporting inclusive value chains (VC), in which resource-poor farmers are included in commercially viable VC opportunities. Strengthening social capital elements between VC actors is key to improve the farmers' livelihood. This article presents a novel impact evaluation method called the VC-Lab to assess the effectiveness of such development programmes, including long-term effects. The method is based on a Public Private Partnership (PPP) in the sorghum VC in Kenya. It consists of different components: (1) a VC analysis; (2) games to assess risk attitude and trust relationships between VC actors; and (3) an agent-based model (ABM) to assess the long-term impact. ABM parameter settings are based on the outcomes of the VC analysis and game results. The level of trust of participating farmers delivering to the participating trader is significantly higher than the level of trust of non-participating farmers in their trader. ABM simulations indicate that in the long run the PPP will lead to higher levels of trust and increased income, whereby training is the key intervention mechanisms. The VC-lab proves to be a valuable evaluation tool. Application of the VC-lab to other VCs, to other commodities and in other countries is needed to test wider applicability of the methodology.

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KEYWORDS
Inclusive value chain; trust; risk; agent-based model; evaluation

1. Introduction

Development aid projects to alleviate poverty in rural areas in developing countries know many forms, from knowledge exchange, to improved practices, to direct investment aid. The idea is that the local population internalises the provided knowledge or improved practices and keeps using the investment after the project has finished. For a better uptake of provided development aid, recently the development of inclusive value chains (VCs) has gained attention. In inclusive VCs, resource-poor farmers and communities are included in local commercially viable VC opportunities. Development programmes are increasingly supporting the development of inclusive VCs through Public–Private Partnerships (PPPs) (Poulton and Macartney 2012). Important aspects in inclusive VC development are the relationships between the VC actors and personal characteristics that govern these relationships, such as trust in a trading partner and risk attitude.

There is a variety of innovation adoption and impact studies on the adaption of improved practices in developing countries (Adiyoga et al. 2009; de Putter; and Witono 2013). Most studies focus on the economic and technical impact of innovations and pay little attention to the role of trust, norms, and values that govern interactions among VC actors. An innovative impact assessment approach is required to assess the effectiveness of such PPPs in building an inclusive VC and

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in reaching the development goals of improved livelihood of resource-poor farmers. This study aims to assess the effectiveness of the 2SCALE PPP and to develop a method to do so.

We focus on a specific case study, a PPP[1] on an inclusive sorghum VC in Kenya within the 2SCALE (Towards Sustainable Clusters in Agribusiness through Learning in Entrepreneurship) programme led by the International Fertilizer Development Center (IFDC). The programme ran from 2012 to 2017 with an approach based on:

(1) Formation of agribusiness clusters (ABC) – local networks between primary producers and between primary producers and technical and financial input providers – to improve competitive intelligence and bargaining power;
(2) Integrating the agribusiness clusters in VCs, with backward linkages to input supply chains and forward linkages to (formal) food chains;
(3) Enabling fair business environments with better access to information and finance, in particular for the weaker actors.

This approach emphasises the role of trust and connectedness at ABC and VC levels in achieving VC efficiency, by encouraging investment and co-innovation along the VC, and by enhancing coordination by introducing forward linkages (for example, formal agreements between VC actors). Within the 2SCALE programme, this study focusses on a PPP in which 2SCALE formed a partnership with Shalem Investments (Shalem), a trading firm and a buying agent of sorghum. Sorghum is traditionally produced by farmers for domestic use to make porridge and ugali. Nowadays sorghum is increasingly used for the production of beer. For this, white sorghum of a specific variety is required. Shalem supplies this sorghum to East African Brewery Ltd, the leading Kenyan beer brewery. Shalem is a family-owned company with offices located in Meru County and operates in the Eastern region of Kenya. Shalem buys sorghum from a network of over 9,000 smallholder farmers organised in farmer groups, offering premium prices to encourage quality and consistency of volumes. In collaboration with 2SCALE, Shalem invests in improved Good Agricultural Practices (GAP), Good Business Practices (GBP), trust building, and stronger relationships in order to ensure a steady sorghum supply in terms of volume and quality.

The question was to assess the extent to which this PPP resulted in stronger relationships between Shalem and farmers and in stronger mutual relationships between farmers within the farmer groups and to assess the effects of those relationships on the value chain's sustainability. For this, we developed a new method to measure if the PPP resulted in changes in trust and the risk attitude. In section 2, we develop the hypotheses on the effectiveness of this PPP in Kenya in strengthening relationships. Section 3 develops the method and materials needed to test the hypotheses. Section 4 gives the results. Finally, section 5 and 6 provide the discussion and conclusion.

2. Theory and hypotheses

Social capital in development programmes is a key contributor to poverty alleviation and development (Collier 2002; Grootaert and van Bastelar 2001; Isham 2002). Uphoff (2000) identifies two distinct types of social capital: structural and cognitive. Structural social capital enables information sharing, collective action and decision-making through established roles, social networks andother social structures supplemented by rules, procedures, and precedents. Cognitive social capital refers to common norms, values, trust, attitudes, and beliefs.

The VC-Lab is based on the theory of change (ToC) that underpins 2SCALEs' support to market transformation (Figure 1) and takes several of these social capital concepts into account. The aid of the 2SCALE programme aims at the adoption of GAP and GBP as well as improving relationships between VC actors. The adoption of GAP and GBP is commonly understood as a rational investment decision that requires capital and labour resources and training. This decision is often influenced by the risk attitude of the farmer, the level of horizontal cooperation between farmers

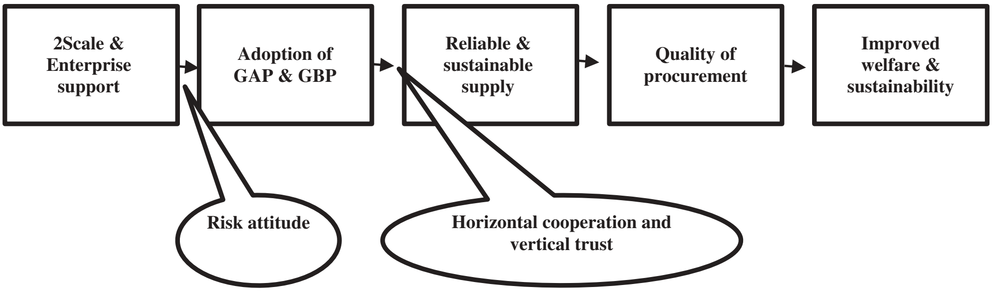

Figure 1. Theory of change to support agriculture value chain development.

in a farmer group, and the level of vertical trust between farmers and the traders of their products. Stable relationships and (contractual) arrangements between farmer groups and traders are important for VC actors to reduce risk and increase their ability to invest (Ruben and Fort 2012). As such, increased trust levels reduce risk and can increase the motivation to adopt improved practices (for example, GAP and GBP) or other innovative (for example, conservation) technologies. This is expected to lead to a more reliable and sustainable supply and increased quality of goods, which, in turn, should result in improved welfare of the VC actors.

2.1. Vertical trust

For smallholder farmers, especially in low and middle-income countries, it is often a challenge to be included in formal VCs. For a successful inclusion of smallholder farmers in a formal VC, trust is a key factor (Blandon, Henson, and Cranfield 2009). Six (2007) defines trust as: 'Interpersonal trust is a psychological state comprising the intention to accept vulnerability to the actions of another party, based upon the expectation that the other will perform a particular action that is important to you'. This implies that when actors are placed in a relational context where trust is involved, trust and action mutually reinforce each other. Interpersonal trust building is a reciprocal process in which both actors interactively build trust. As Six (2007) explains 'A's trust in B is confirmed, that is, B acts reciprocally according to A's pattern of expectations and trust is increased. If A perceives B to be sufficiently trustworthy, A will act in a way that makes himself vulnerable to the actions of B; B, in turn, will perceive A's action as indications of A's trust – and hence A's trustworthiness – and will probably act according to A's expectations, which will be perceived as confirmation of A's initial trust.' This will result in a positive trust uptake.

In an open market situation, trader-to-seller trust in a VC is important, because it concerns direct trading partners, not only now, but also in the future. VC actors are not integrated into the same company and do not work under the same management. As such, VC actors are independent, but trade with each other based on formal agreements (for example, a contract) and informal agreements (for example, trust). Formal and informal agreements can both be present in a relationship between VC actors and are usually in balance (Das 1998). If the level of trust in another actor is low, then the level of formal agreements is likely to be high.

Therefore, repeated positive feedback results in higher trust levels. Shalem is offering good prices prior to the planting of sorghum and keeps its promises about these prices. Brokers and other traders often do not have such agreements, and if they have, they often break these agreements. Therefore, we expect farmers working with Shalem to have higher trust levels in Shalem than those farmers working with other traders have in these other traders. This results in the following hypothesis:

H1: Farmers supplying to Shalem have higher levels of trust in Shalem compared to other sorghum farmers in their sorghum traders.

2.2. Horizontal cooperation

According to Ostrom (2003), horizontal trust is the core link between networks and collective action and the most relevant factor to provide voluntary cooperative action. It is enhanced when individuals are trustworthy and connected to each other within institutions that reward honest behaviour. Trustworthy individuals are often considered honest and similarly, a truthful person will possess honesty. Honesty is the extent to which an individual sticks to agreements.

By being involved in successful cooperatives, farmers can work together and are able to exchange agricultural techniques, and together they have more means to access financial inputs and markets. 2SCALE aims at forming of ABCs – local networks between the primary producers themselves and between primary producers and with various technical and financial input providers – to improve competitive intelligence and bargaining power. Therefore, we formulate the following hypothesis:

H2: Farmers of the groups supplying sorghum to Shalem have higher mutual trust and show less free riding behaviour than farmers of groups supplying sorghum to other traders.

2.3. Risk attitude

Risk is mainly guided by risk perceptions that in turn may be influenced by the risk attitude (Barham et al. 2014; Feder, Just, and Zilberman 1985). Resource-poor farmers in developing countries are generally risk-averse, and farmers' choices are consistent with increasing relative risk aversion and decreasing absolute risk aversion (Binswanger 1980; Vargas Hill 2009; de Brauw and Eozenou 2014). So, farmers participating in new crops and new programmes can be expected to have lower risk aversion than farmers that do not participate. Therefore, we defined the following hypothesis:

H3: Farmers who participate in the 2SCALE programme have a lower risk aversion than non-participating farmers.

3. Materials and methods

The VC-Lab method compromises three components:

(1) Value Chain Analysis (VCA);
(2) Value Chain Games (VCG) among participating farmers and non-participating farmers; and
(3) Agent-based Model (ABM).

Figure 2 provides the linkages between these three VC-Lab components. The VCA maps the VC, providing insight into the VC configuration, the VC actors and their relationships, and the product and financial flows. This is input for the VCG and ABM. With the VCG, the level of trust and risk aversion of individual VC actors inside and outside the PPP are measured. The results of the VCG

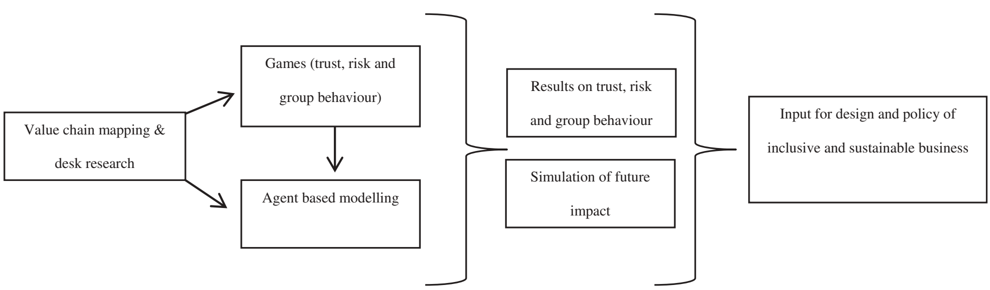

Figure 2. Visual overview method VC-lab.

are input in the ABM. Finally, with the ABM an ex-ante impact assessment of the long-term effect of the PPP is simulated. The results of the VCG and ABM are used to assess the effectiveness of the PPP and to provide policy advice on inclusive and sustainable business.

3.1. Value chain analysis

The VCA consisted of two parts: (1) a field visit and (2) a desk research. In 2015, we organised a 5-day field visit to map the sorghum VC. During the mission, the relevant key VC actors were visited, that is, farmers, traders, input suppliers and various service providers. For the sessions with the farmers, we used Focus Group Discussions (FGD). FGDs are commonly used to encourage participants to talk to one and another, exchange ideas, ask questions and comment on each other's point of view (Kitzinger and Barbour 1999). For other stakeholders (for example, IFDC staff, extension workers, input suppliers, transporters, banks, traders), we used semi-structured interviews. In each interview, we used a guideline with among other topics on trust, risk and the role of formal and informal contracts. The VCA was complemented with a desk study to gather data on production statistics and production seasons through a literature review and consultation of statistical data sources.

3.2. Value chain games

In the VCG, data is gathered about vertical and horizontal trust, horizontal cooperation, and risk attitude. Experimental economics offers methods like games to gather behavioural data (Cardenas and Carpenter 2008). With such games, hypothetical and socially desired answers can be avoided as much as possible. We used three games, which were customised to the context of the sorghum VC in Kenya:

(1) Trust game (Berg, Dickhaut, and McCabe 1995), to measure vertical and horizontal trust;
(2) Voluntary Contribution Mechanism (VCM) game (Andreoni 1995), to measure horizontal cooperation;
(3) Risk preference game using paired lottery (Holt and Laury 2002), to measure risk attitudes.

To resemble reality as much as possible, the games were played with coins representing real money, and every participant could gain a certain amount of money while playing the games. Each coin represented 1 Kenyan Shilling (KES[2]). At the end, all farmers were paid the amount they had won in the games. Each farmer was compensated for transport costs in addition to the amount they earned in the games.

Games were played during a field trip from 20 June until 2 July 2016 in Meru County, Kenya. Two researchers gathered the data, each supported by a local research assistant, who also translated to and from the local languages Kimeru and Swahili. Assistants were extensively trained on objectives and processes of the games in trial games with local programme partners. Each researcher visited one farmer group per day and played all the games with the farmers in the group. Together the games lasted for 5 to 6 hours. Where necessary, games were played anonymously, in the sense that the participants did not know their counterpart. In addition, the researchers simulated the behaviour of the sorghum trader in the games, as playing the games with the farmers and the actual trader could jeopardise their real-life relationships. The collected data were directly stored in a database during the games to ensure quality. A short survey was taken from each farmer during payment after the games were done.

3.2.1. Trust games

Trust games were used to measure three trust parameters:

- Farmers' trust in the sorghum trader;
- Farmers' trust in their group members, and

- Trust update, which is the development of trust when the trader fulfils his promise (positive trust update) or does not fulfil his promise (negative trust update).

In the trust games, farmers were randomly divided into two groups, group A and B. Each farmer in group A received an initial amount of 10 coins. Each farmer in group A sent a fraction of the coins to a farmer in group B, but the farmer in group A did not know who. This amount was recorded and tripled by the game leaders before it reached the farmer in group B. The farmer in group B decided how much of this amount to send back to the farmer in group A. This amount was recorded and forwarded to the farmer in group A. Trust was measured as the fraction of the coins the farmer in group A sent to the farmer in group B. Each farmer earned the amount of KES he or she won in each trust game. Farmer A received the amount not sent to B plus the amount received from B. Farmer B received the tripled amount received from A minus the amount sent to B.

To measure farmers' trust in their group members two trust games were played between farmers (1 from group A to B, and 1 vice versa). To measure the farmers' trust in a trader, one trust game was played between farmers and a Shalem (half of the farmers in the treatment groups) or their normal sorghum trader (half of the farmers in the control groups) and a new sorghum trader (the remaining half in all groups). To measure trust update, three consecutive trust games were played between the farmers and a 'new sorghum trader'. In these games, the farmers were divided into four groups. Each group received a prior specified return. Group 1 received half of the amount of coins they had sent to a new sorghum trader in return, to measure negative trust update. Group 2 received the amount they sent to a new sorghum trader in return, as a reference. Groups 3 and 4 received 1.5 and 2.0 times the amount of coins they sent to the new sorghum trader in return, to measure positive trust update. The trust update is a farmer's trust level in a new sorghum trader, that is, amount of coins sent to the new sorghum trader, in a game minus his/her trust level in the new sorghum trader in the previous game. In all games, it was specifically mentioned to whom the farmers were sending their coins. Prior to each trust game, it was clearly stated that the trader did not take the decision in the games, but the researchers defined how the respective traders would have decided.

3.2.2. VCM game

In the VCM games, all farmers in a group were asked to contribute a share between 0 and 10 coins of their initial amount of 10 coins to a public account, and to stock the remaining coins in a private account. The amount in the public account was doubled and then equally shared among all farmers. A farmer's trust in his group was measured as the fraction of the 10 coins this farmer contributed to the public account. Each farmer earned the amount of KES he or she won in each VCM game, so the amount in the private account plus the amount received from the public account. We measured farmer's honesty (free riding) as the relative amount of coins compared to the initial endowment of 10 coins send to the public account in a VCM game played with the same 144 farmers who played the group trust game.

3.2.3. Risk preference game

In the risk preference game, a multiple price list was used with six choices between option A, 'win a certain amount of money' or option B: 'flip a coin' (head: amount of money, tail: nothing). The amount at which a farmer decides to switch from option B to option A was used as a measure for his risk attitude. The six values in the multiple price list in option A 'win a certain amount of money' were 10, 20, 30, 40, 50, or 60 KES. The risk preference game was played individually. Each farmer earned the amount of KES he or she won in this game. The risk attitude was only estimated for farmers who showed a consistent risk attitude. Farmers who choose the certain option in a game with a specific certain amount and the gamble option in a game with a higher certain amount, and farmers who switched multiple times between the options were excluded. Farmers were divided into subgroups, depending at which certain amount they switched from gamble to certain. To estimate relative risk aversion λ for each group, the exponential utility function $U(r) = 1 - -e^{-\lambda \cdot r}$ was used, where r is the amount of money to gain. For example, for the 'Certain from 10 to 60 KES' group, the utility of getting 10 KES for certain ($U\left(\frac{10}{60}\right) = 1 - e^{-\lambda\frac{10}{60}}$)was set equal to that of the gamble between flipping a coin with winning 60 KES for head and 0 KES for tail $\left(0.5\,U\left(\frac{60}{60}\right) + 0.5\,U\left(\frac{0}{60}\right) = 0.5\left(1 - e^{-\lambda\frac{60}{60}}\right) + 0.5\left(1 - e^{-\lambda\frac{0}{60}}\right)\right)$ and this equation was solved for λ.

3.2.4. Order of games played

Table 1 provides the order in which the games were played.

3.2.5. Survey

After the games, farmers were asked questions on personal characteristics (age, gender), production (land area with sorghum, yield of most recent harvest), marketing (trader, period of relationship with trader) and trust (in other group members in sorghum trader). Trust was measured using a 5-point Likert scale. The other questions were open questions.

3.2.6. Farmer selection

The games were conducted at nine farmer groups supplying sorghum to Shalem (treatment groups) and six farmer groups supplying sorghum to another trader (control group). In each group, games were played with 16 farmers, in total of 240 farmers. The research team selected the 9 treatment groups from a list of 22 farmer groups that had delivered sorghum to Shalem at least 1 year. The research team also randomly selected 16 farmers from the member list of these groups to participate in the games. Since no list of farmer groups for the control groups was available, these were selected based on Shalem knowing the group leader or contact information provided by treatment group leaders. For the control groups, the random selection of game participants could not occur because no group member list was available. Therefore, each group leader was asked to select 15 other members of their group and to provide for a venue. In some situations, a group consisted of several subgroups, each with their own leader. According to Shalem, the control groups were farmers who had not been targeted by Shalem and as such did not take part in the 2SCALE initiative. When conducting the games with the control groups, during the games it appeared however that 29 farmers (30%) had supplied sorghum to Shalem, Six out of them have supplied Shalem for multiple years. However, these farmers only supplied Shalem one time, and it occurred very recently, so no long-term relationship had been established. Therefore, we could still use the results of these farmers in the study.

Table 1. Order of the games played with sorghum farmers in Meru County, Kenya.

#	Game order
1	Trust game between farmers, with farmers in group A as first movers
2	Trust game between farmers and a sorghum trader. Group A farmers were dealing with the Shalem (treatments groups) or their normal trader (control groups), all group B farmers were dealing with a new sorghum trader
3	Trust game between farmers, with farmers in group B as first movers
4	Trust game between farmers and a new sorghum trader 1. All farmers were dealing with a new sorghum trader
5	Trust game between farmers and the new sorghum trader 2. All farmers were dealing with the new sorghum trader from game 4
6	Trust game between farmers and the new sorghum trader 3. All farmers were dealing with the new sorghum trader from game 4 and 5
7	Risk preference game
8	Voluntary contribution mechanism public goods game 1
9	Voluntary contribution mechanism public goods game 2
10	Voluntary contribution mechanism public goods game 3
	Short survey and payment

3.3. Agent-based model

In order to explore the options for cooperation in the Meru County sorghum value chain in the long run, an agent-based model has been implemented, based on the value chain mapping, survey reports, and the experiments' outcomes. Agent-based modelling is applied for the reasons mentioned by Gilbert (2008):

- Ontological correspondence: realistic representation of the VC with many individual farmers and only a few VC partners;
- Heterogeneity: the great diversity of farmers with respect to the farm area, farming skills, personal characteristics, financial resources, productivity, etc., can be modelled with realistic distributions based on the available survey and game data;
- Representation of the environment: data on seasonal variations of growing conditions and market price are available;
- Agent interactions: there is extensive research history in particular on agent-based modelling of individual trust relations (for example, Ramchurn, Huynh, and Jennings 2004; Sabater and Sierra 2005); individual agent interactions can be modelled based on distributions of trust and risk attitude as measured in the games;
- Bounded rationality: agents act upon relatively simple decision rules, and there is no additional assumption or models of optimisation required;
- Learning: agents can learn from the outcomes of previous actions; models for updating their trust in other agents based upon experience have long been available (see, for example, Jonker and Treur 1999).

The agent-based simulation is implemented in NetLogo (Wilenski 1999). The present subsection describes the simulated entities and processes, limitations of the modelling approach, and the observable outputs from the simulation. The simulation and documentation are available from OpenABM.[3]

Active entities in the simulation represent plots of land, farmers who cultivate the land, and traders who contract farmers to deliver their produce. The present simulation sets up a single trader. Suppliers of farmer inputs and the brewery are not represented as agents. The farmers are organised in fixed groups, headed by one of the members. The groups are not represented as entities; all farmers have a state variable pointing to their group head and a state variable comprising the set of group members. Farmers maintain a list of traders they know and maintain an associated list of trust they have in each of the traders. In addition to their trust in the processor, farmers maintain trust in their group and have a risk attitude and an honesty parameter as personal properties that affect their decisions. Honesty is the extent to which an agent sticks to agreements.

The agents operate in an environment where natural conditions and market prices are generated for each growing season. A simulation run typically includes approximately 10,000 farmers (in groups of 16) and a single processor, and typically spans a period of 10 years or 20 growing seasons, with a time step of one sorghum growing season of half a year.

Figure 3 represents a time step in the simulation cycle. The processor sets the contract conditions. Then, the farmers decide whether to apply for a contract, based on their risk attitude and trust in the processor and may apply for a group loan based on the trust in their group members. Depending on their cash balance or the availability of a loan, the farmers can invest in inputs, services and skills, which determine – together with random natural conditions – the yield. Market price and natural conditions are randomly drawn from user-specified intervals. Then, if they have a contract, farmers decide whether to sell to Shalem or sell on an alternative market. If a farmer group as a whole delivers more than a certain prior agreed amount to Shalem, all members of the group receive a group delivery bonus per kg sorghum delivered. Reasons to sell on an alternative market are urgent financial need and opportunism. The probability of selling to

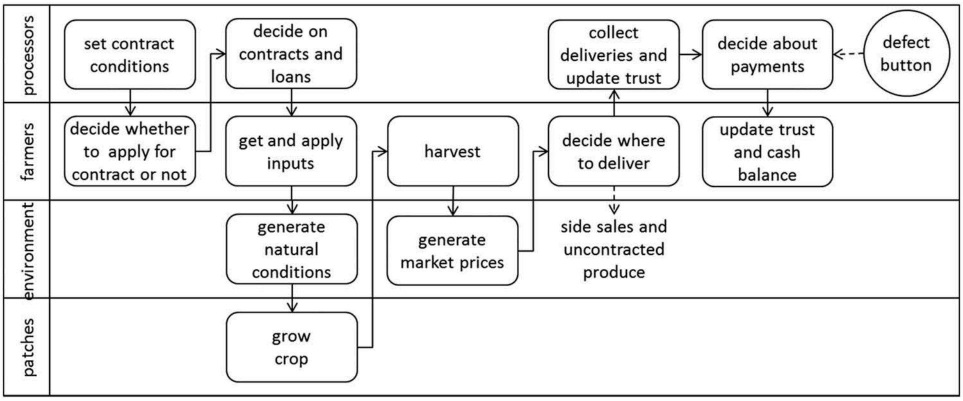

Figure 3. Process overview of a time step representing a cropping season.

an alternative market depends on a farmer's honesty parameter and on the current market price. Selling to an alternative market negatively affects the processor's trust in the farmer. In addition, it negatively affects group trust among the farmers, because of lower group delivery bonus and mutual responsibility for group loans. Thus, compliance and defection by the farmers are simulated based on personal characteristics set in the user interface, cash balance resulting from previous growing seasons, and market prices. The processor will always comply unless the user presses the DEFECT button during the simulation to study the effects on the system of such behaviour. The DEFECT button makes the processor defect on timely paying the contract price for one time step.

Farmers' trust in traders, traders' trust in farmers, and farmers' trust in their group members are updated in each time step according to slow positive and fast negative trust dynamics (Jonker and Treur 1999). Trust is modelled to increase with each positive experience and to decrease more rapidly with each negative experience.

Farmers base their decisions whether to invest in high-quality inputs and skills, and enter into contracts or not, on information they get from the 2Scale programme and on personal characteristics of risk aversion and trust. Evaluation of risky alternatives is modelled using risk-averse utility functions of the form $U(r) = 1\text{-}e^{-\lambda r}$, where λ represents an agent-specific risk aversion parameter and r represents some return. Trust is expressed as a real variable on the interval [0, 1], where 1 represents the belief that the other party will certainly comply, 0 represents the belief that the other will certainly defect, and 0.5 represents full uncertainty. Similarly, honesty is modelled as a farmer's personal characteristic, which expresses the probability that the farmer will not defect on a contract and side sell when another trader offers a price exceeding the contract price.

Key observable outputs from the simulation are the number of contracts, contracted area, harvested volume, volume delivered on contract, side selling due to financial need, side selling due to opportunism, farmers' gross revenue, and evolution of trust levels. These observable outputs can be monitored in the simulation's user interface.

3.3.1. Parametrisation

The simulation is initialised with data gathered in the value chain mapping, the baseline survey for the quantitative evaluation of 2SCALE, and games played with farmer groups in Kenya. Since random variations are generated for sorghum market price and natural conditions affecting the harvest, variations may occur in the outcomes of simulation runs with equal parameter settings. Therefore, we present results as average over 30 replications for each combination of parameters, which is sufficient to keep standard errors below 5 per cent for the relevant observations. Table 2 displays the default parameter settings.

The harvested volume is modelled to depend on natural conditions, quality of inputs used and farmers' skills. A farmer agent's skills are generated at random from the interval between the

Table 2. Default parameter settings for the agent-based simulation.

Parameter	Value	Unit	Parameter	Value	Unit
Farms	9,216		Minimal natural conditions	0.5	
Minimal farm gate price	14,000	KES/ton	Savings	FALSE	
Maximal farm gate price	30,000	KES/ton	Minimal risk aversion [a]	0.00005	1/KES
Local market price	14,000	KES/ton	Maximal risk aversion [a]	0.0002	1/KES
Aggregator availability	80	%	Minimal initial trust	0.2	
Optimal inputs costs	14,000	KES/ha	Maximal initial trust	1	
Labour costs	22,000	KES/ha	Minimal honesty	0.2	
Loan amount	30,000	KES/ha	Maximal honesty	1	
Costs loan & insurance	5,000	KES/ha	Configure from game data	FALSE	
Postharvest costs	2,900	KES/ton	To be delivered	5,000	Ton
Transaction costs market	1,000	KES	Farmers contract price	25,000	KES/ton
Transaction costs contract	0	KES	Maximal group bonus	2,000	KES/ton
Basic expected yield	1.2	Ton/ha	Bonus lower bound	80	%
Improved inputs yield	5		Positive trust update factor	0.05	
Minimal skills factor	0		Negative trust update factor	0.10	

[a]Relative risk aversion assumed in range [1, 4], amount at stake 20,000 KES.

Kenyan sorghum farmers' trust in a new sorghum trader (average amount of coins farmers sent to a hypothetical new sorghum trader) in three consecutive trust games for four categories of returned amount by the hypothetical new sorghum trader relative to the amount the farmer sent.

	Returned amount of coins by the hypothetical new sorghum trader in the trust game relative to the amount the farmer sent			
	0.5	1.0	1.5	2.0
Trust in trust game 1	2.70	3.55	3.50	3.28
Trust in trust game 2	2.40	3.10	3.33	3.45
Trust in trust game 3	1.98	3.65	3.58	3.87

minimal-skills-factor and 1. This way a harvest distribution is generated that includes farmers with very low and high productivity, similar to the findings in the baseline survey.

Agent characteristics with respect to trust, honesty, and risk attitude can be initialised, at the users' choice, by random generation from ranges specified as input parameters (Table 2) or by random drawing from the results of the games played in Kenya for each agent. The default ranges included in Table 2 are chosen so that simulation outputs approximately match the outcomes produced with game results. Farmers are assumed to spend the revenue from a single harvest during the following season (Savings set to FALSE in the results reported here).

4. Results

4.1. Value chain analysis

Figure 4 presents an overview of the sorghum VC and its main actors in the PPP. Farmer can receive seeds, fertilisers, pesticides, and other inputs from input suppliers and loans from financial institutions. Farmers bring most of the sorghum to collectors, that store the sorghum on behalf of traders. Sometimes, opportunistic brokers can also buy sorghum from farmers, but usually at a lower price because they appear when the farmers are in need of cash. The brokers sell their sorghum to traders. The traders deliver the sorghum to the brewery.

4.2. Value chain games

4.2.1. Descriptive analysis of game participants

Farmers in both treatment and control groups were similar in age (42 years) and gender with about two-third female and one-third male farmers (Table 3). The control groups had a lower share of

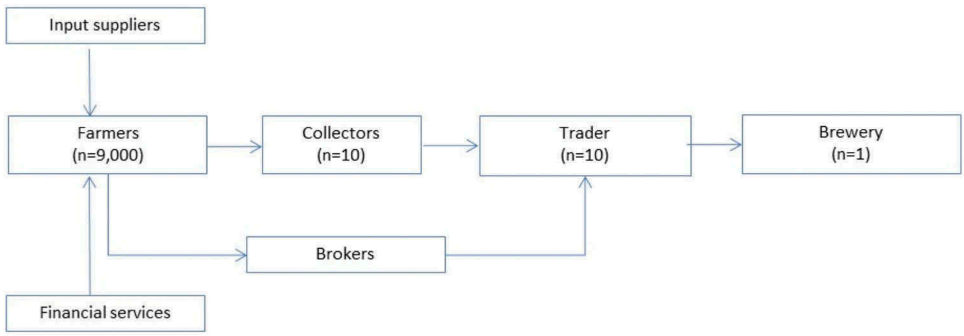

Figure 4. A simplified sorghum value chain.

Table 3. Descriptive statistics of the Kenyan sorghum farmers participating in the behavioural games.

Variable	Treatment (N = 144)	Control (N = 96)	Significant
Age (years)	41.8	42.1	
Male (%)	35.0	30.0	
Female (%)	65.0	70.0	
Acre	5.2	3.6	**
Group member (%)	82.6	67.7	
Production (kg)	2,341.0	1,254.0	***
Productivity (kg/acre)	926.0	613.0	***
Received input loan (%)	49.0	19.0	***
Received production loan (%)	22.0	10.0	**

normal members compared to group leaders than the treatment group (p = 0.054), probably due to the fact that the researchers randomly selected the game participants in the treatment groups, whereas the group leader chose the game participants in the control groups. Farmers in the treatment groups cultivate more acres with sorghum than farmers in the control groups. This can relate to the fact that the farmers delivering to Shalem have a guaranteed market for their sorghum and are aware of the price they would receive for their produce. The productivity per acre is also higher for treatment groups than for control groups. This could be a direct result of the training and coaching on GAP provided by the programme. The treatment groups received more input and production loans than the control groups, most likely due to a guaranteed sorghum market provided through the programme which makes the participating more credible for local financial service providers. Farmers in the treatment groups had been delivering sorghum to Shalem for up to 15 years, with most farmers only 2 or 3 years (n = 52 and n = 30, respectively).

4.2.2. Game results

4.2.2.1. Vertical trust. Trust in Shalem of the farmers in the treatment group is significantly higher (p = 0.0001) than the trust of the control group farmers in their normal trader and trust in new traders (Figure 5). Trust of farmers in the control group in their normal trader was significantly higher than trust in a new broker/trader. In addition, the results from the survey after the games showed that farmers in the treatment group had an average trust level in Shalem of 4.65 (out of 5), which is significantly higher (p = 0.0001) than the average trust level of 2.18 farmers in the control group had in their normal trader. No significant difference was observed in trust in a new trader between the treatment and control group. This confirms the hypothesis H1 that farmers supplying to Shalem have higher levels of trust in Shalem compared to trust levels of other sorghum farmers in their regular trader. Differences in farmer trust levels in Shalem could not be explained by the descriptive variables presented in Table 2.

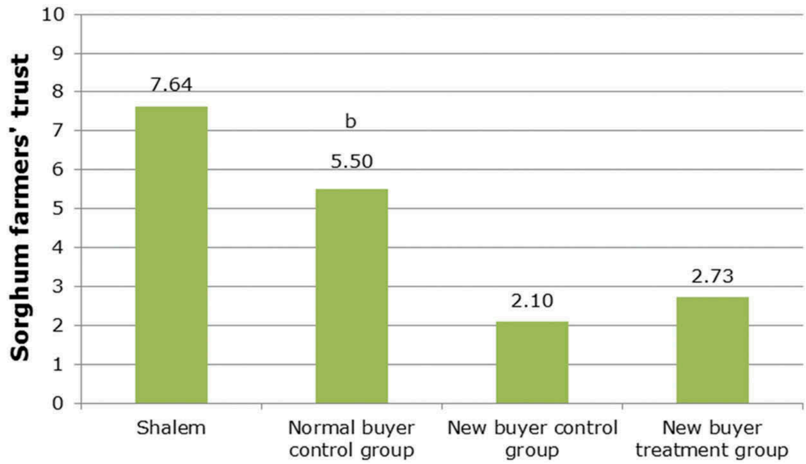

Figure 5. Trust levels of sorghum farmers in different sorghum traders in Meru county, Kenya (averages are significantly different at $p < 0.0001$).

Table 4. Reasons of farmers' trust in their sorghum trader in the treatment and control groups (in %, more than one answer possible).

	Treatment (in %)		Control (in %)	
Reason for trust in their sorghum trader	Yes	No	Yes	No
Provided training on farming practices	33	0	3	0
Offers good price	29	1	13	34
Keeps promises	24	2	7	22
Certainty of the market	22	0	2	5
Provided inputs (seeds, loans, other)	14	0	2	0
Good timing collection & payment	6	10	1	6
Trader is honest	6	0	1	7
No other trader available	1	0	5	0

Farmers supplying to Shalem mentioned in the survey following the games that the most important reasons for their trust in Shalem are that Shalem provides training, offers a good price, keeps promises, and provides a guaranteed market (Table 4). Offering GAP and GBP training to the farmers, building and maintaining a good relationship between VC actors and being trustworthy are important elements of the 2SCALE intervention in the PPP. These intervention elements from the PPP thus seem to aid in the high level of trust of participating farmers in Shalem.

4.2.2.2. Horizontal cooperation. Table 5 shows no significant differences in group trust between the farmers in the control groups and the farmers in the treatment groups. Group trust with the farmers giving on average 5.8 and 5.3 coins to the public account was relatively low compared to the trust in Shalem (7.6) but in line with the trust in other traders (5.5). The average amount given to the public account decreased with every round meaning that farmers copied free riders. We cannot confirm hypothesis H2 that farmers of the groups supplying sorghum to Shalem have higher mutual trust and show less free-riding behaviour than farmers of groups supplying sorghum

Table 5. Group trust and free riding (treatment group, n = 144, control group, n = 96).

Variable	Treatment	Control	t-Value	Significance level p
Trust in VCM game 1	5.8	5.3	1.361	0.175
Trust in VCM game 2	3.9	3.4	1.323	0.187
Trust in VCM game 3	3.5	3.0	1.253	0.212

to other traders. Differences between farmers in group trust levels could not be explained by the descriptive variables presented in Table 2.

4.2.2.3. Risk attitude. Table 6 shows the results of the risk attitude game for the 182 farmers (110 of the treatment and 72 of the control group) who showed consistent risk perception results. Most farmers were risk-averse. Almost all farmers preferred already 10 KES for certain above the possibility to win 60 KES, resulting in a risk aversion level of 3.72 (out of 5). Significantly more ($p < 0.05$) farmers in the treatment groups (73%) had a risk aversion of 3.72 compared to 43 per cent in the control groups. So, farmers in the treatment groups were more risk-averse than farmers in the control groups. Hypothesis H3 that sorghum farmers who participate in the 2SCALE programme have a lower risk aversion attitude than non-participating farmers is not confirmed in our study.

4.3. ABM simulation forecasts

The main emergent properties to be observed are the numbers of contracts and loans, average farm income (gross margin), and the total availability of sorghum to the processor, in order to fulfil its contractual obligations towards downstream value chain partners. Figure 6 shows the outcome dynamics for both the default settings and the game-based settings. In both cases, most farmers initially enter into contracts and groups apply for loans. Then, the number of loans decreases and

Table 6. Results from the risk perception game.

Description choices	Switch point	Risk aversion	Treatment		Control	
			#	*In%*	#	*In%*
Certain from 10 to 60 KES	0	3.72	80	73%	31	43%
Gamble at 10 KES, certain from 20 to 60 KES	1	1.86	8	7%	11	15%
Gamble from 10 to 20 KES, certain from 30 to 60 KES	2	1.24	4	4%	10	14%
Gamble from 10 to 40 KES, certain from 40 to 60 KES	3	0.93	4	4%	8	11%
Gamble from 10 to 50 KES, certain from at 60 KES	4	0.74	3	3%	5	7%
Gamble at 10 KES, certain from 20 to 60 KES	5	0.62	3	3%	4	6%
Gamble from 10 to 60 KES	6		8	7%	3	4%
Total			110	100%	72	100%

Figure 6. Dynamics of some emergent outcomes from a simulation configured with default settings (upper row) and a run with game-based settings (bottom row).

after that the number of contracts. As can be seen from the lower gross margin for non-contracted farmers in the right-hand graphs, in particular, the less productive farmers lose their contracts. In both cases, the processor can in most seasons fulfil its contractual obligations. The fluctuations in the observable variables are caused by variations of natural growing conditions and market price. Results in the top and bottom rows in Figure 6 are comparable, except for the stronger decline of the number of loans in the runs with default parameters. In the game-based settings, several agents have a trust-update of zero, and they maintain their trust in the group and keep applying for loans, even if group members defected. The average gross margin over the last four seasons of the game-based settings simulations is slightly higher than in the simulations with the default parameters (18 thousand vs 16 thousand KES/season). Since the results from simulations with default parameters are similar to those based on game outcomes, we assume that sensitivity analysis and simulations of alternative scenarios can be based on variations of the default parameters for trust, risk aversion, loyalty, contract price, and farmers' skills.

Figure 7 provides insight into the causes of the decline in the number of contracts. The middle graph shows side selling for two reasons. Farmers side sell when in urgent need for cash. Group members, who stand surety, must redeem their loans, lose trust in the group, and no longer apply for loans. The middle graph shows that also opportunistic side sales by contracted farmers under high market prices occur (cf. left-hand graph), and continue after the loans system has collapsed. The defecting farmers lose the traders trust (cf. right-hand graph) and contracts.

The simulation results show a decline in harvest volumes and deliveries on contracts over the simulated period, but not to an extent that the processor cannot fulfil its current contract. However, many farmers remain poor and there is no room to satisfy additional demands from downstream value chain partners.

4.3.1. Sensitivity analyses

Sensitivity analyses of the input variables were performed to identify their effect on model outcomes. The results of the sensitivity analyses can point to promising interventions to strengthen the VC. As an example, simulations were run with the minimal skills factor raised to 0.5, thus raising the average skills factor from 0.50 to 0.75. In this example, simulated average deliveries on contracts and gross margins are roughly doubled (Table 7). Improving the weaker producers' skills could be a promising intervention.

If the contract price is 1,000 KES/kg lower than in the default case, the number of deliveries to the Shalem is 11 per cent lower, side sales 10 per cent to 13 per cent higher, and affected farmers' gross margins 10% lower compared to the results with the default settings. To increase the contract price could be a promising intervention to strengthen the VC.

Lower loyalty parameter settings (maximum honesty decreased from 1.0 to 0.5) resulted in 13 per cent higher farmers' gross margins but reduced the number of total deliveries to Shalem with −16 per cent. Several mechanisms in the simulation contribute to this result. First, a lower contract price reduces average gross margins directly. Second, when market prices more often exceed the

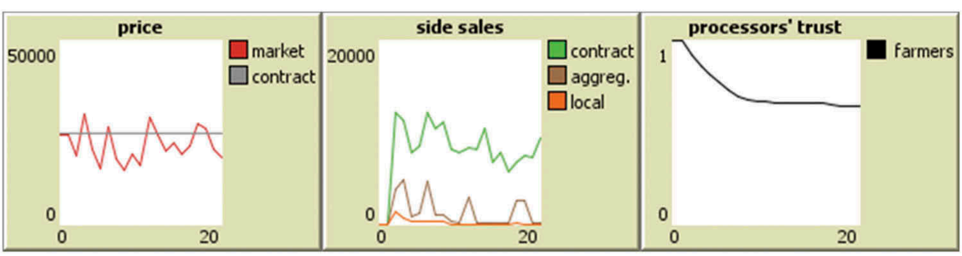

Figure 7. Causes of the decline of loans and contracts (game-based settings).

Table 7. Average outcomes for last 4 seasons of a 10-year period from simulations with improved skills ('minimum-skills' = 0.5); average outcomes of 30 runs.

Outcome	Harvest (tons)	# loans	# contracts	Delivery (tons)	Gross margin (KES)
With default parameters	9,910	8	3,775	7,843	15,629
- minimal-skills set to 0.5	18,535	3,921	7,912	15,860	36,469
- increase (%)	87	–	110	102	133
With game data	10,362	1,363	3,679	6,840	17,852
- minimal-skills set to 0.5	18,137	2,318	5,994	12,923	33,496
- increase (%)	75	70	63	89	88

Table 8. Accumulated shortage of deliveries to fulfil the processor's downstream contracts and number of seasons in which shortages occurred, under different assumptions about the relation between local harvest and farm-gate price.

Harvest-price relation	Accumulated shortage over 10 years	# seasons with shortage
No correlation	1,148	2.0
50/50	1,972	2.6
100% inverse relation	2,925	4.7

contract price farmers are more often tempted to side sell; deduction of the group-wise assigned delivery bonuses also affects farmers who complied with their contracts. Third, farmers who do not comply may be excluded from future contracts or group-wise loans. In addition, in times of bad natural conditions or low market prices, farmers without a contract may have insufficient financial resources to invest in good seed, chemicals, and services for the next season. Interventions that convince farmers to comply with their contracts, even when market prices are high, could strengthen the VC.

To analyse the impact of different levels of trust of the farmers in Shalem, we vary the range from which initial trust is randomly drawn. With initial trust drawn from the range [0.2, 0.5], the total volume delivered on contacts is 8 per cent less, and the average farmer's gross margin is 5 per cent less compared to the results with the default range. If initial trust is drawn from [0.8, 1.0]; then, the volume delivered on contracts is 9 per cent more, and the average farmer's gross margin is 6 per cent more compared to the results with the default range.

Sensitivity to a change in risk attitude of the farmers was low with maximum changes in total volume delivered up to 3 per cent and in farmers' gross margins up to 4 per cent and compared to the results with the default risk attitude range. When contract prices were lower (that is, 23,000 KES/kg), the impact of a change in risk attitude was larger with maximum changes in total volume delivered up to 31 per cent and in farmers' gross margins up to 17 per cent.

The simulations assumed full independence between the randomly generated sorghum market price and local sorghum harvest as influenced by randomly generated natural conditions because no data on this relation is available. This relation is complex due to the influence of world market price and the price and local harvest of potential substitute crops, such as maize. In a sensitivity analysis, we tested the impact of this assumption by simulating two alternative scenarios. In the first scenario, we assuming a full inverse relation between market price and harvest volume (minimal natural conditions imply maximal farm-gate price; maximal natural conditions imply minimal farm-gate price) and in the second scenario a 50/50 mix of the full inverse relation and independent relation. Table 8 shows that the stronger the relationship between market price and harvest is, the higher the simulated market price will be and the larger the shortage for the processor will be. The latter due to increased side selling. This finding stresses the urgency for the processor to find ways to convince farmers to comply with their contracts.

5. Discussion

In this study, we developed a new method, the VC-lab, to evaluate the impact of the 2SCALE programme to strengthen the inclusive sorghum VC in Kenya. Trust between the sorghum farmers and Shalem, the sorghum trader in this programme, was found to be of importance. Indeed, games results showed that trust in Shalem of farmers delivering sorghum to Shalem was higher than the trust of other farmers in their regular trader. An agent-based model showed that keeping this trust at a high level is important for farmers to remain delivering within this VC. Horizontal cooperation between farmers in a farmer group and risk attitude were not found to differ between farmers delivering to Shalem and farmers delivering to another sorghum trader.

In our study, we gathered data from nine farmer groups of farmers having a contract with Shalem and six farmer groups without such a contract. We needed 16 members from each group to participate in the games. Although Shalem had 22 farmer groups delivering sorghum, many groups had less than 16 members. Therefore, we only sourced from the larger farmer groups delivering to Shalem. Almost all of the larger groups were included in the study. Although many farmer groups exist in Meru State in Kenya that produces sorghum, finding six farmer groups without a contract with Shalem proved to be more difficult than finding the farmer groups delivering to Shalem. This was mainly because the contact details of the group leaders were not readily available. Through advice from group leaders delivering to Shalem and personal contacts of Shalem staff, Shalem was able to find 6 farmer groups that had more than 16 members and were willing to participate in the study. Because no comparison has been done with other farmers, it is unclear how representative the risk attitude and trust results of these farmer groups and farmers are for all farmer groups and farmers producing sorghum in Kenya. However, it was not the aim of the study to be representative for the Kenyan sorghum producers. In our study, we also found that most sorghum farmers were risk averse. The lower risk aversion in the control groups might be accidental, because of the low number of control groups. In general, low-risk attitude results are expected to be more widely applicable since it is very similar to other studies on trust among smallholder farmers, as identified in the literature (Holt and Laury 2002; Toledo and Engler 2008). Given these limitations, care should be taken when extrapolating the results of this study to other sorghum value chains in Kenya or to other value chains, other commodities and other countries.

A limitation in the present sorghum supply simulation in Meru County is that it focusses on the farmers' decisions on contracts, loans, and compliance and on the trust relations and dynamics between farmers and processor; relations with farmers' input suppliers and processor's customers are ignored. Another limitation is that a single crop is considered and that no farmers' decisions on alternative crops are considered in the simulation. Data to model such decisions were not available.

Our study showed a higher sorghum productivity per hectare among farmers supplying to Shalem compared to farmers supplying to another trader. This could be related to the training on GAP the farmers supplying to Shalem received. Another potential cause could be that the farmers supplying to Shalem are more intrinsically motivated to increase productivity as they have a certain trader of all they produce and are assured of a minimum price for this amount.

One of the goals within the 2SCALE PPP with Shalem was to increase the level of trust between sorghum farmers and Shalem. Our results show that farmers delivering to Shalem have more trust in Shalem than other farmers have in their regular trader. This suggests that the activities performed by Shalem to increase trust have been effective. However, trust building requires several investments of Shalem, for example regular staff visits to farmer groups, extra services and training for farmers, and a good sorghum price for farmers. Benefits of the increased trust are an increased amount of sorghum to be sourced and lower transaction costs of sourcing sorghum. In the end, the benefits of increased trust should outweigh the increased costs for Shalem to make this a long-term viable business strategy. To analyse this, a cost-benefit analysis could be used.

Side selling by farmers who have a contract with Shalem decreases the amount of sorghum available for Shalem. Side selling is if such farmers deliver part of their harvest to other traders or on the open market. Side selling could be seen as a breach of the contract with Shalem and should be prevented at all costs. However, multiple reasons for side selling exist and need not be malevolent. For example, farmers can have an urgent need for cash to buy food, to pay the school fee for their children or to pay the hospital bill of a family member. Now and then, farmers that have a contract with Shalem indeed sell part of their harvest to other traders. As long as farmers do not have savings or cannot access loans, it can be expected that side selling will occur for urgent cash needs, even when all conditions are favourable such as a high price, a guaranteed market, and cheap/free extension service and training. Side selling needs to be considered by traders in the contracts with such small-scale farmers.

The VC-lab showed to be a valuable tool to assess the effectiveness of the 2SCALE programme aiming to develop an inclusive sorghum value chain in Kenya. Application of the VC-lab to other value chains, to other commodities and in other countries is needed to test the wider applicability of the VC-lab methodology.

6. Conclusion

We developed the VC-lab to assess the effectiveness of the 2SCALE PPP in building an inclusive value chain in the sorghum value chain in Kenya and in reaching the development goals of improved livelihood of resource-poor farmers. Farmers' trust in the participating sorghum trader Shalem was significantly higher than other farmers' trust in their normal trader. With an agent-based model, the long-term importance of trust was simulated. It is essential for a stable supply of sorghum that the sorghum trader Shalem provides a stable and high contract price against uncertain alternatives for farmers. Improving farmers skills is an effective way to increase total sorghum production and volume supplied to the processor. We conclude that the 2SCALE PPP was effective in increasing trust levels between sorghum farmers and Shalem and that the livelihood of resource-poor farmers is expected to improve, if all PPP activities are continued. The VC-lab showed to be a valuable tool to assess the effectiveness of the 2SCALE programme aiming to develop an inclusive sorghum value chain in Kenya and improve the livelihood of participating farmers. Application of the VC-lab to other value chains, to other commodities and in other countries is needed to test the wider applicability of the VC-lab methodology.

Notes

1. This PPP is led by the IFDC and includes the Base-of-the-Pyramid Innovation Centre (BoP Inc.) and the International Centre for development-oriented Research in Agriculture (ICRA). The programme was supported by a grant of the Ministry of Foreign Affairs (MoFA) of the Netherlands through the Directorate-General for International Cooperation (DGIS).
2. One Euro equalled around 110 KES when the games were conducted in Kenya.
3. https://www.comses.net/codebases/5785/releases/1.1.0/.

Disclosure statement

No potential conflict of interest was reported by the authors.

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