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Impacts of contract farming in domestic grain chains on farmer income and food insecurity. Contrasted evidence from Senegal

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ABSTRACT

Contract farming in export chains may upgrade producers' livelihoods thanks to the access to improved inputs and high-value markets. We tested the hypotheses that contracts in domestic grain chains improve farmers' incomes and reduce food insecurity. We studied the rice value chain in Senegal, where the national agricultural bank and rice millers draw up production and marketing contracts. We applied instrumental variables and propensity score matching models to a dataset of 470 observations to correct selection bias. We found that as a financial device, marketing contracts had no impact on agricultural practices, product quality or income but reduced food insecurity by mitigating price seasonality. Production contracts had a positive impact on the income of producers who were excluded from bank credit but included implicit interest and insurance costs, meaning that these producers make less profit than those financed by the bank. Policies supporting the modernization of domestic grain value chains in West Africa should promote credit insurance systems and support the negotiation of an incentive price in contracts.

1. Introduction

Contract farming is an intermediary form of vertical coordination that has been expanding in the private sector since the 1960 s in response to the demand for high-quality products (Swinnen and Maertens, 2007). It is likely to appear when uncertainty and asset specificity are high, such as in the trade of products that are perishable, difficult to store and transport and probably of heterogeneous quality (Minot and Sawyer, 2016). Since the 1980s, this institutional innovation has been increasingly used in Africa where agricultural and input markets often fail. Contract farming in Africa mainly concerns tropical, horticultural and animal products produced by small-scale farmers and exported to northern markets (Swinnen and Maertens, 2007).

The scientific literature over the last 15 years mainly reports on the positive impacts of contract farming on family farms. Contractors support producers in improving the quality of their products by providing access to improved inputs and technical advisory services (Reardon et al., 2009). Such contracts increase yields, farm gate prices and income (Bellemare, 2012; Bolwig et al., 2009; Girma and Gardebroek, 2015; Leung et al., 2008; Maertens and Swinnen, 2009; Maertens and Vande Velde, 2017; Minten et al., 2009; Mishra et al., 2016; Miyata et al., 2009; Rao and Qaim, 2011; Saenger et al., 2013; Simmons et al., 2005; Trifković, 2016; Wang et al., 2014; Warning and Key, 2002).

Contract farming is widely documented in export value chains (VCs) for high value products (Minot and Sawyer, 2016), but little has been published about the impacts of contract farming in domestic grain chains. Indeed, contractual arrangements in these VCs are less likely to be adopted because demand for high-quality products is limited, thereby preventing the appearance of a premium. Furthermore, the low perishability of grain facilitates side selling (Swinnen et al., 2010). Nevertheless, contract farming recently appeared in certain domestic grain chains in sub-Saharan Africa. Factors that favor such contracts include demand for high-quality cereals (Demont and Ndour, 2015), state policies implemented after the world food price crisis in order to modernize domestic food chains (MA, 2009) and support from international organizations. As a result, contract farming is increasingly implemented by private companies in Madagascar (Bellemare, 2012), Benin (Maertens and Vande Velde, 2017), Ghana (Ragasa et al., 2018) and Senegal. However, questions remain about the capacity of chains targeting high-quality staple domestic markets to increase producers' income.

Furthermore, in the case of staple chains, analysis of the impacts of

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contract farming needs to be extended to food insecurity. The implementation of contract farming in grain chains could create competition between sales and domestic consumption. Few studies have examined the impact pathways between contract farming and farmers' food insecurity. Minten et al. (2009) found that contract farming in the horticultural sector shortens lean periods. Bellemare and Novak (2017) found that contracts improve producers' income and therefore reduce the hungry season, especially for households with more children. The present paper will add research to this body of evidence.

Finally, the existing literature considers that producers market their products either in traditional VCs through spot transactions or in modern VCs through contracts. However, producers sometimes combine contracts and spot transactions because these two types of marketing fulfill specific functions. For instance, contract farming provides access to improved inputs and profitable markets, while spot transactions ensure rapid payment (Masuka, 2012), access to credit for unexpected expenses and outlets for products rejected by contractors (Mujawamariya et al., 2013). Such a combination of marketing modes is sometimes cited in the literature, but without its impacts on farmers' income being documented (Da Silva, 2005; Gow and Swinnen, 1998; Rao and Qaim, 2011).

The objective of this paper is to assess the impact of two types of contract on farmers' incomes and food insecurity in a domestic grain chain. The hypothesis is that contracts improve farmers' incomes through access to credit, improved inputs and technical advice, thereby increasing yields and improving quality (Reardon et al., 2009). Contracts also reduce farmers' food insecurity by increasing their income (Bellemare and Novak, 2017). The paper helps fill the knowledge gap relating to the impacts of contract farming in domestic grain chains. It breaks down the impacts of contract farming and of the combination of two marketing modes on farmers' incomes while highlighting different pathways from contract farming to food insecurity. It also helps understand the conditions under which contract farming may fail to generate higher incomes for producers. Finally, it provides recommendations for policies aimed at modernizing domestic food chains in West Africa.

The rice VC in the Senegal River valley provides empirical insight into the impact of contract farming in domestic staple chains in sub-Saharan Africa. We use a sample of 470 observations specifically developed for this study. We apply instrumental variable and propensity score matching models to correct selection bias. We compare the income and food insecurity of producers adopting two types of contracts. Marketing contracts were set up by the government in order to secure the repayment of loans to the national agricultural bank and to support rice millers' supplies. Its price takes the paddy quality into consideration. Production contract were established by rice millers to ensure the quantity and quality of their supplies. Millers provide farmers with credit inputs and, sometimes, technical support, and the farmers' repayments are made in paddy.

Section 2 presents the empirical background of contract farming in the Senegalese rice VC. Section 3 describes the method used while Section 4 presents the results. Section 5 concludes.

2. Background

2.1. Agricultural policies and modernization of the rice value chain

Imports of rice in Senegal increased by 2.2% per year between 1960 and 2011 (Fig. 1) and accounted for 80% of domestic consumption between 2001 and 2010. The particularity of Senegal among West African countries is that 98% of rice consumption refers to broken rice, a byproduct of milling (Hathie and Ndiaye, 2015). Domestic production therefore faces competition from cheap imports. However, the shift in demand towards higher-quality products also concerns broken rice (Demont et al., 2013).

Since independence in 1964, several programs have been implemented by the government and international organizations with a view to developing the rice VC in Senegal (Fall, 2006). In the wake of the world price crisis, and following the example of several governments in Africa, the inter-ministerial council created a new national program for rice self-sufficiency (MA, 2009) with the support of the Coalition for African Rice Development. This program aimed at expanding land used for rice farming from 55,000 ha in 2008 to 175,580 ha in 2012 in order to increase national production from 535,000 tons of paddy to 1,500,000 tons. These goals were subsequently postponed until 2017 (MA, 2014). The main target area is the Senegal River valley which accounted for 80% of domestic rice production in 2014 (USDA, 2015). The two main agencies implementing these policies are the national agricultural bank (French acronym CNCAS) and the national company which supports irrigated agriculture in the Senegal River valley (French acronym SAED).

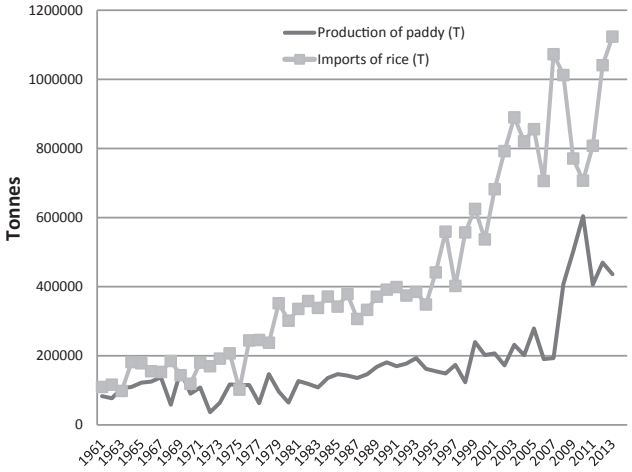

Fig. 1. Rice imports and production in Senegal (data from FAOSTAT). Note: the paddy to milled rice conversion factor is 0.67.

Since 1964, agricultural financing has been used extensively by the government to support rice farming. The CNCAS is now the main source of credit in the Senegal River valley because diversification (income from horticulture, breeding, trade, handicrafts and salaried work) and other sources of credit are limited. In 2005, diversification accounted for between 20% and 30% of rice production costs and only 2% of farms took out a loan from a small-scale processor (Fall, 2006). Small-scale producers access to credit from CNCAS via producer organizations. These organizations obtain a loan if they have repaid previous loans, if they farm irrigated land and if their technical production specifications are validated by SAED. Producer organizations also enable the collective purchase of seeds, fertilizers and herbicides. Producer organizations with a loan from CNCAS buy fertilizer with a 50% subsidy and the rate of interest on the loan is also subsidized, thereby reducing it from 12.5% to 7.5%. Nevertheless, in 2005, delays in obtaining the loan reduced the associated impact on technical efficiency and on farmers' incomes. The poorest farmers used fewer inputs than recommended because they did not have sufficient cash-flow to purchase inputs in advance (Fall, 2006). Finally, producer organizations sell the paddy to repay the bank loan.

The CNCAS has experienced difficulties in being repaid. The government has intervened four times since 1991 to implement turnaround plans. The last intervention cost FCFA 13.6 billion[1]. Producer organizations that do not repay loans cannot obtain another loan until either they or the government repays the previous one.

In the Senegal River valley, rice is grown in two seasons on irrigated land. Intensive agricultural practices include the use of certified seeds, synthetic fertilizers and herbicides as well as mechanization for

[1] 1 euro = 655.957 FCFA.

threshing and sometimes for land preparation and harvesting. By 2014, support for intensification provided by SAED since 1973 had enabled producers to reach yields of 6.7 t/ha in the dry season and 5.3 in the wet season.

A total of 45,000 family farmers are located in the Senegal River valley (Gergely and Baris, 2009). In 2010, 39.5% of these were considered to be living on less than $1.9 a day (ANSD, 2010) and 16.1% were affected by food insecurity, measured by the frequency of consumption of different food groups (WFP, 2014).

2.2. Modernization of the rice value chain

The VC that we characterized as *traditional,* in which producers market their paddy through spot transactions, has been operating since the 1970s. Small-scale processors use mills to husk the rice. The quality of rice is low as it contains impurities and is not sorted by grade, in addition to having a moisture content that may be inappropriate for cooking. The small-scale processors purchase the paddy from farmers and producer organizations through spot transactions with relational proximity. They check the quality of paddy visually for impurities. Their simple husking technique does not require complex quality indicators in transactions. Producer organizations that benefit from a credit from the CNCAS market their paddy to the small-scale processors and repay the loan to the bank with the money they receive from the sale. The selling price of paddy varies considerably over the season. This traditional VC accounted for 87% of paddy produced in 2014 in the Senegal River valley.

Between 2009 and 2014, eight Senegalese processors used their profits and sometimes the subsidies from development agencies to invest in modern husking techniques. These units can theoretically process up to four tons of paddy per hour and perform functions improving rice quality, such as drying, cleaning and sorting. These processors are located in the Dagana *département* which accounted for 93.5% of the 26,019 ha farmed by small-scale producers in the 2014 dry season in the Senegal River valley. Their modern husking techniques need to be combined with specific paddy quality criteria to yield broken and whole grain rice with no impurities and with the right moisture content. The technology also requires sufficient volumes of paddy to cover their high depreciation costs. In 2014, each rice miller processed between 2000 tons and 13,000 tons of paddy out of a total of 45,000 tons processed using modern technology. These quantities were limited by the quantities of paddy that rice millers were able to collect.

2.3. Contracts

USAID supports SAED and the CNCAS in developing the rice VC through the “Feed the Future” program. Marketing contracts were introduced in 2011 to secure the quantity and quality of the supplies received by the millers and to support the repayment of the loans granted by the CNCAS. Marketing contracts are part of the credit system described above. The paddy supplied by the producer organizations repays the loans. With the contract, millers pay the money directly into the bank account of the producer organization, which in turn repays the bank. The bank promotes the use of contracts by both producer organizations and millers. The participating producer organizations must obtain a loan from the CNCAS, be located within 50 km of the miller and be able to supply at least two tons of paddy. The millers who use marketing contracts are located close to the main roads that crosses the Dagana *département* (Fig. 2). All marketing contracts use the template negotiated within the inter-professional association. This includes information about the quantity, quality and price of paddy. A suggested price is negotiated within the inter-professional organization and is taken into consideration in the marketing contracts. In the 2014 dry season, the suggested price was 125 FCFA/kg. The contract price also takes account of the moisture content (which must be between 12% and 14%), the consistency of the variety and the proportion of impurities (which must be less than 1%). If the quality criteria are not met, millers can refuse the paddy or reduce the price. In the 2014 dry season, marketing contracts were used to sell 15,000 tons of paddy supplied by 98 producer organizations bringing together 2000 small-scale producers growing rice on a total area of 4000 ha.

Production contracts were created by rice millers in 2010 to ensure the quantity and quality of their supplies. Both rice millers and farmers can initiate such a contract. Farmers must grow at least 2.5 ha of irrigated rice or be part of a producer organization, in addition to being located within the collection radius of 50 km from a miller. Millers who use production contracts are concentrated in the north of the department and their collection radius does not cover the whole territory (Fig. 2). In 2014, production contracts were used by 71 producer organizations farming 3500 ha and included 1500 producers. Production contracts accounted for 5.6% of the production of paddy in the Senegal River valley. In a context of limited sources of credit, production contracts are used by producer organizations indebted to the CNCAS. In the 2014 dry season, only 2.6% of producers who adopted a production contract belonged to a producer organization that had the right to apply for a CNCAS loan. The in-kind contract is written and its content can be adapted to the needs of producers for seed, fertilizers, herbicides and/or mechanized services. The miller may also provide technical support and have the power of decision over the technical itinerary. The quality of paddy required is the same as in a marketing contract. The price per kilogram is negotiated before the harvest and farmers have reported having little power to influence it because they have no alternative way to fund rice growing during the subsequent season. The average purchase price during the 2014 dry season was FCFA 104 per kilogram. If a contract is breached, a new contract is usually established with closer supervision by the rice miller. None of the producer organizations that had a production contract in the 2014 dry season supplied more than the quantity of paddy equal to the value of the credit.

2.4. Combined marketing modes

Small-scale farmers in the Senegal River Valley combine collective sales through producer organizations with individual sales (Colen et al., 2013). They participate in producer organizations to obtain access to credit and inputs. Once a season, the members of a producer organization conduct a collective sale to repay the loan. This collective sale is carried out through a spot transaction, a marketing contract or a production contract. Moreover, small-scale farmers undertake individual spot transactions. The numbers and volumes of these transactions are determined by household needs. The advantages of individual transactions are that they are flexible and ensure quick cash payment.

3. Materials and methods

We evaluate the impacts of adopting contracts (D) on farm performance (Y). The approach consists in collecting data at farmer level to compare the outcomes of producers participating in contracts ($D = 1$) with those of non-participants ($D = 0$). Nevertheless, participation in contract farming is not randomly decided due to purposive targeting of firms and self-selection of beneficiaries (Barrett et al., 2012). Accordingly, the difference in outcome could be due to selection bias. Eq. (1) addresses this issue, the selection bias being the term $E[Y(0)/D = 1] - E[Y(0)/D = 0]$:

$$E[Y(1)/D = 1] - E[Y(0)/D = 1] + E[Y(0)/D = 1] - E[Y(0)/D = 0] \quad (1)$$

We use impact evaluation models to reduce selection bias and extract the average treatment effect on the treated (ATT). The ATT is the difference between the average outcome of treated observations and the average outcome of similar non-treated observations:

$$\text{ATT} = E[Y(1)/D = 1] - E[Y(0)/D = 1] \quad (2)$$

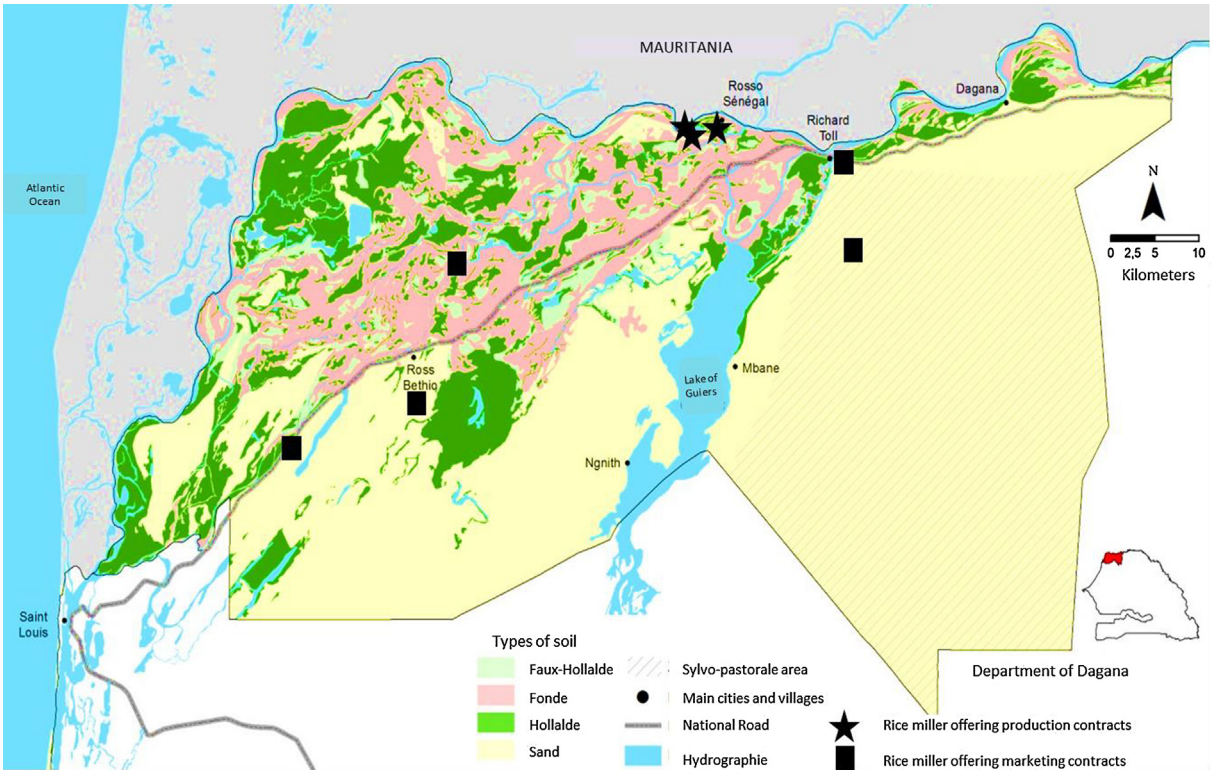

Fig. 2. location of rice millers in Dagana department in 2014.

3.1. Models

The combination of parametric and non-parametric models strengthens the robustness of results because they rely on different hypotheses (Barrett et al., 2012). First, we use instrumental variable (IV) models, which effectively correct endogeneity when meeting the exclusion restriction condition. In the study, the risk of measurement error is low as producers have no interest in misreporting their participation, they have the same ability to remember data and we cross-checked price and quantity data with the leaders of the producer organizations and with the agricultural advisors. The issues of omitted variables and reverse causality might, however, be raised (Bellemare, 2012). There could be omitted variables at the producer level that determine participation or non-participation in credit and therefore in contracts. Exploratory interviews showed that these could be the existence of previous shocks hindering yields and preventing credit reimbursement, or farmers' preference not to reimburse the credit. There could also be omitted variables at the organizational level, such as the risk preference or the leader's experience in rice marketing. The IV models aim to reduce such sources of endogeneity.

We use two types of instrumental variable models. The income, yield and costs outcomes (presented in Section 3.5) are continuous variables and thus require the use of linear models. Endogeneity is corrected using a two-stage least square model (Angrist and Pischke, 2009). Moreover, the food insecurity variables are bounded. We use a Tobit model censoring the response variable if $Y_i = 0$. In Stata14®, two-stage least square models were computed using the ivreg2 package (Baum et al., 2016) and Tobit models were computed using the ivtobit command.

In the ordinary least square model, i is the individual, α is the constant, β is the coefficient associated with the individual and contextual characteristics of producers ($\boldsymbol{X}_i$), γ is the coefficient associated with the dummy participation variable (D_i) and ϵ is the error term.

$$Y_i = \alpha_1 + \beta_1 \cdot \boldsymbol{X}_i + \gamma_1 \cdot D_i + \varepsilon_i \quad (3)$$

The use of instruments generates an unbiased estimate of the treatment by isolating the part of the treatment variable that is independent from the unobserved characteristics that affect the outcome. The first-stage model is a linear regression of the treatment variable on the instrument or vector of instruments $\mathbf{Z}_i$ and the vector of covariates. Linearity ensures that first-stage residuals are not correlated with fitted values or covariates (Angrist and Pischke, 2009).

$$D_i = \alpha_2 + \beta_2 \cdot \boldsymbol{X_i} + \gamma_2 \cdot \boldsymbol{Z_i} + \mu_i \quad (4)$$

The predicted values from this model are used in the second-stage estimation (5) to retain the variations in producer outcomes that are generated by the instrument. In (5), the ATT is the estimation of the coefficient γ_3 associated with the predicted values of contract participation.

$$Y_i = \alpha_3 + \beta_3 \cdot \boldsymbol{X}_i + \gamma_3 \cdot \widehat{D}_i + \varepsilon_i \quad (5)$$

The challenge when using IV models is to identify instruments that meet the exclusion restriction condition (Wooldridge, 2010). In Section 3.6, we present the instruments used in the models and discuss why we feel that they meet this condition. In the case of two-stage least square models, the statistic for under-identification of instruments holds if excluded instruments are not correlated with the endogenous regressor. The Cragg-Donald Wald statistic for weak identification holds if the instruments are sufficiently correlated with the endogenous regressor. When models are over-identified, the Sargan-Hansen test of over-identifying restrictions checks that there is no correlation between the instruments and the error term of the structural equation. In the case of Tobit models, instrument validity is tested through the Anderson Rubin weak-instrument-robust test statistics by using the weakiv command (Finlay et al., 2013).

Second, we use propensity score matching models (PSM) (Rubin, 1974) that generate results similar to randomized estimates when there is no significant omitted variable (Khandker et al., 2009). The propensity score for the participation PS_i of an individual is calculated using a probit density function.

$$PS_i = \Pr(D = 1/\boldsymbol{X}_i) \quad (6)$$

Control and treated individuals are matched by minimizing the difference between the probability of their participation (Rubin, 1974): $\min_{k \in C} ||PS_i - PS_k||$, where k is the observation from the control group in the common support region (C) matched with individual i from the treated group. The nearest neighbor matching algorithm compares one treated observation with the closest ones in terms of probability of participation (Caliendo and Kopeinig, 2008). We keep the five closest observations, and matching is achieved with replacement. This algorithm reduces the estimation bias (Dehejia and Wahba, 2002). For both treatments, the caliper is fixed at 20% of the variance of the propensity score, thereby minimizing the mean of the square of the error term (Austin, 2011).

PSM relies on the strong ignorability hypothesis (Heckman et al., 1999). First, the common support hypothesis means that there are sufficient observations in the treated and control groups with the same probability of participation (Caliendo and Kopeinig, 2008). Second, conditional independence means no variable is omitted (Imbens, 2004). We tested the sensitivity of the results yielded by PSM with the Rosenbaum bounds test (Rosenbaum, 2005), which tests the robustness of results to the existence of an omitted variable which would imply changes in propensity scores.

3.2. Data collection

The study area is the Dagana *département*, the core rice-producing area in Senegal and the only place where contracts were found in 2014. We conducted a cross-sectional survey. Sampling was carried out in three steps. First, irrigation unions bringing together small-scale producers were selected.

Second, we randomly selected producer organizations after stratification according to the types of marketing, i.e. spot transactions, marketing contracts, production contracts and rice growers who did not grow rice in the 2014 dry season because of indebtedness. Treated and control groups were differentiated during this step. Stratification was carried out by agricultural advisors using exhaustive SAED databases and information from rice millers. Contract farmers were oversampled to obtain sufficient observations in the treated groups. We did not use correction weights in models because there is no heteroscedasticity, sampling was not endogenous and weights would not aim at correcting the heterogeneity of contracts impacts (Solon et al., 2013). The 90 randomly selected producer organizations represented the 1105 producer organizations that grew rice on 26,019 ha in the 2014 dry season.

Third, within each producer organization, we randomly selected six producers. The same questionnaire was used for all respondents. When one producer could not be found, we interviewed the next one on the list. Data were collected in May 2015. The data concern the 2014 dry seasons and were collected before the harvest of the following dry season, both to reduce the chance of confusion and to better detect food insecurity.

3.3. Sample

The sample used for data analysis includes 470 observations: 141 producers conducting spot transactions, 130 with marketing contracts, 155 with production contracts and 44 producers who did not grow rice in the 2014 dry season. Some additional 124 observations of producers marketing through spot transactions were not used for comparison because they are significantly more diversified and therefore do not comply with the common support hypothesis.

Details of the treated and control groups are provided in Fig. 3. We compare producers who used a marketing contract with producers who used a CNCAS loan and sold their rice through spot transactions. We compare producers who had a production contract with two groups of producers in order to discuss the impacts of production contracts. The first control group is the same as the one used to compare producers using marketing contracts. We also compare producers who had a production contract with rice growers who were excluded from the CNCAS and, for this reason, did not grow rice in the 2014 dry season. These producers are nevertheless considered to be rice growers because they estimate that 74% of their income in previous years came from rice growing, their producer organizations were on the list of rice growers and they farm irrigated land.

3.4. Control variables

The variables influencing participation in contracts and the outcomes (Table 1) were identified during discussions with millers and producers and in the literature (Barrett et al., 2012; Bellemare, 2012; Maertens and Swinnen, 2009; Reardon et al., 2009). Differences in characteristics between contracted and non-contracted farms may be due to discrimination by rice millers and self-selection of producers.

We first discussed the selection of farmers' characteristics by rice millers. Millers claimed to select producers mainly based on observable characteristics. The distance between the farm and the miller determines participation in contracts because the millers' collection radius is around 50 km. Moreover, the volume of supplies available from farmers matters for contracting companies (Barrett et al., 2012). Rice millers in Dagana *département* claimed to select producers and producer organizations on the basis of the irrigated area they farm. In this paper, we use the number of members of the producer organization as a proxy for the surface area farmed by the producer organization because part of the data about the surface area was missing. Contracting companies also select farms based on non-land assets (Reardon et al., 2009). Some millers stated that they prefer to purchase paddy from the wealthiest households with the highest number of active members and the most experience. A previous study of French beans in Senegal also identified the fact that ethnicity influenced participation in contracts (Maertens and Swinnen, 2009). One of the millers' selection criteria less frequently cited in the literature is farmers' access to warehouses, as it enables better control of the moisture rate. Nevertheless, millers reported that recent increases in the regional milling capacity and competition with traditional processors caused them to be less exacting with regard to these characteristics.

Factors influencing self-selection in contracts were also discussed with producers. Uncertainty in terms of access to credit influences participation in contracts because the farms in the study area are specialized and the credit opportunities are limited. Moreover, we hypothesize that the "Degree of farm specialization" variable captures information about how diversification could influence farmers' food insecurity, because the main non-rice crop in the study area is tomato, which is mainly marketed (Fall et al., 2010). Furthermore, households headed by women and elderly people seemed to have less information about contracts, preferring spot transactions. More dependent households might also display a weaker performance. In contrast, ownership of a vehicle seems to improve farmers' connections with rice millers".

Some selection criteria might be specific to marketing and production contracts, or might not influence all the outcomes presented below. We nevertheless use all the control variables in each model because there is no consensus on the non-influence of certain variables on certain outcomes (Rubin and Thomas, 1996).

The survey was carried out in the third year the contracts were being used, so there is little chance that structural variables concerning the producers were influenced by participation. We nevertheless collected prior-treatment values for certain control variables: ownership of a vehicle, the total value of assets, and access to storage facilities. The developed surface in 2014 (that may differ from the farmed surface) cannot have been influenced by participation because of the high land development costs.

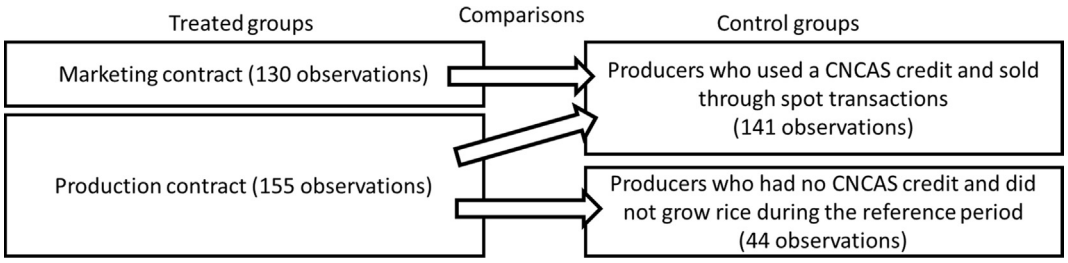

Fig. 3. Treated and control groups.

Table 1
Description of control variables.

Covariates	Description
Developed area	Surface area (ha) that could be irrigated owned by the grower in 2014.
Number of active members	Number of members above 15 and able to work
Experience in rice growing	Number of years the head of the household has grown rice
Age of head	Age of the household head in years
Value of non-land assets in 2010	Total value (FCFA) of assets owned by the households in 2010 at prices they could have been sold (recall data). Agricultural assets include tractor, water pump, thresher, husker, cart, small and large ruminants, storage facilities and others. Non-agricultural assets include car, motorbike, bicycle, television, phone, radio and others.
Dependency ratio	Ratio (%) of the number of inactive members (children below the age of 15 and members unable to work) to the total household size
Female-headed household	Dummy for a female-headed household
Wolof ethnic group	Dummy for ethnic group of household head is Wolof, the major ethnic group in Senegal
Outside storage (dummy)	Dummy for the household had to store at least a part of the paddy outside in 2010
Degree of farm specialization	Share (%) of income from paddy in total income of the household. Perception of household head expressed as a percentage.
Number of members in the producer organization	Number of members in the producer organization of which the respondent is a member.
Ownership of vehicle in 2010	Dummy for ownership of a car and/or a motorbike in 2010

3.5. Outcome variables

Outcome variables are income, production costs, yields and food insecurity. Income indicators are profit per kilogram and price per kilogram. We define Inc_{ic} as the income from the contract sale of producer i, P_{ic} as the contract price per kilogram and Q_{ic} as the quantity of paddy in kilograms marketed through contracts.

$$Inc_{ic} = P_{ic} \cdot Q_{ic} \tag{7}$$

Producers undertake only one contract sale per season. In contrast, they may realize several spot transactions. Inc_{iT} is the total income from marketing through contract and spot transactions:

$$Inc_{iT} = P_{ic} \cdot Q_{ic} + \sum_{j=1}^{N} P_{ijs} \cdot Q_{ijs} \tag{8}$$

where N is the number of spot transactions realized by farmer i, P_{ijs} the price per kilogram of the spot transaction j and Q_{ijs} the quantity in kilograms marketed through this spot transaction.

We define C_{ikg} as the production cost of one kilogram of paddy, C_{iT} as the total production cost and Q_{iT} as the total quantity of paddy produced by farmer i.

$$C_{ikg} = \frac{C_{iT}}{Q_{iT}} \tag{9}$$

Q_{iA} is the quantity of paddy dedicated to uses other than marketing, such as self-consumption, religious gifts and payments in kind. Therefore:

$$Q_{iT} = Q_{ic} + \sum_{j=1}^{N} Q_{ijs} + Q_{iA} \tag{10}$$

π_{iC} is the profit per kilogram when producer i completes a sale by means of a contract.

$$\pi_{iC} = \frac{Inc_{ic} - C_{ikg} \cdot Q_{ic}}{Q_{ic}} = P_{ic} - C_{ikg} \tag{11}$$

π_{iT} is the profit per kilogram when considering all transactions realized by producer i (contract plus spot).

$$\pi_{iT} = \frac{Inc_{iT} - C_{ikg} \cdot (Q_{ic} + \sum_{j=1}^{N} Q_{ijs})}{Q_{ic} + \sum_{j=1}^{N} Q_{ijs}} \tag{12}$$

Prices of collective sales were cross-checked with the representatives of the producer organizations and technical advisors. Input costs include labor, capital depreciation and interest paid to the bank, in addition to conventional inputs (seed, fertilizers, etc.). The opportunity cost of self-produced inputs or of inputs purchased with payments in kind was calculated based on demand. If there was no demand, the opportunity cost was the production cost. Otherwise, the opportunity cost was equal to the selling price during the period considered (Boussard, 1987). Rice yields are in kilogram per hectare.

Food insecurity was measured using the Household Food Insecurity Access Scale (HFIAS), which focuses on the respondent's perception about the access dimension of food insecurity (Coates et al., 2007). HFIAS is correlated with other indicators such as the coping strategies index, the household hunger scale, the food consumption score, the household dietary diversity scale and the self-assessed measure of food security (Maxwell et al., 2014). The indicator is based on nine questions, each associated with three frequency options. It enables the indicator to be calculated, ranging from 0 (food security) to 27 (maximum food insecurity). We also broke this indicator down to highlight the aspects of quantity (from 0 to 15) and quality (from 0 to 9) in food insecurity.

3.6. Instrumental variables

We need to identify variables that are strongly correlated to participation in contracts, but not to the outcomes. In the literature assessing

the impacts of contract farming with IV models, the instruments are usually proxies of the transaction costs of contract implementation (Trifković, 2016). The instruments may be related to risk perception, such as respondent trustworthiness (Warning and Key, 2002), or risk aversion to participate in contract farming (Bellemare, 2012). They are also related to the geographical distance of the farm from the rural bank (Ramaswami et al., 2006), the village leader (Miyata et al., 2009) or the production area and extension offices (Girma and Gardebroek, 2015). Other instruments concern the magnitude of contract farming in the area because its provides farmers with easy access to contracts: they include the total contracted surface or number of companies (Tilahun et al., 2015), the number of integrated farms in a village and the number of years since the first contract was set up (Trifković, 2016). Finally, the instruments relate to access to information through the social position of the producers (Girma and Gardebroek, 2015), their link with officials (Bolwig et al., 2009) or participation in a producer organization (Rao and Qaim, 2011).

Echoing this literature, which we completed with exploratory interviews, we included several potential instruments in the questionnaire. These were: the geographical distance from the house of the leader of the producer organization; the relational proximity to the leader; a Likert scale concerning the perception of credit uncertainty; the transport duration from the rice millers; and the transport duration from the main road. Furthermore, we calculated the distances (in kilometers) from the farm to the rice millers and to the main road. The two instruments used in the models are those that best meet the exclusion restriction according to the Focus Group Discussion and to discussions with colleagues with a good knowledge of the study area. They also are the ones that perform best according to the Cragg-Donald Wald statistic, the Sargan-Hansen test and the Anderson Rubin weak-instrument-robust test statistics.

The first instrument is producers' perception of credit uncertainty. Uncertainty is a source of transaction costs and leads to the implementation of vertical coordination mechanisms such as contract farming (Barrett et al., 2012). Producers' perceived credit uncertainty was measured using a Likert scale ranging from zero to six in terms of the interviewee's degree of agreement with the following statement: "The household has the ability to fund rice growing with a credit". Zero expressed complete agreement and six non-agreement.

The second instrument is the distance between the village of the producer organization and the rice miller. Distance between the contracting company and producers is considered as a source of transaction costs (Barrett et al., 2012). The implementation of contracts requires several interactions. The main steps are the identification of a partner, the management of administrative documents (which requires several journeys by the leaders of the producer organizations to the firm, the bank or the input suppliers), the follow up of the inputs and paddy deliveries and the follow-up of the payment. As a result, the geographical distance between the partners increases the negotiation, monitoring and enforcement costs (Gilly and Torre, 2000). The distance was measured in kilometers using the Google Maps® geographical information system and based on discussions with rice millers and producers concerning the roads used to reach the mills or villages.

The exclusion restriction condition implies that the instrument only influences the outcome through the endogenous variable (Wooldridge, 2010). For this reason, "it is challenging to find a truly exogenous IV that is also strongly correlated with participation in contract farming" (Barrett et al., 2012: 721). We consider that farmers' perceptions of credit uncertainty influence participation in contracts because these contracts were set up to secure credit reimbursement. Farmers therefore participate in contracts in order to secure their access to credit. In contrast, we consider that perceived credit uncertainty has little likelihood of influencing farmers' outcomes (other than those generated by the contractual form) because this perception concerns only the uncertainty relating to access to credit (and not general uncertainty), and the sources of credit in the area are all related to contracts. Indeed, no farm in the sample entirely self-funded rice production because they all have low capital, specialize in rice farming and display high rice production costs (on average FCFA 517,195 per ha). The two forms of credit available to farmers come from CNCAS, which established marketing contracts, and rice millers, who established production contracts. Other sources of credit were very limited, as interlinked transactions concerned only 0.91% of the farms in the dry season 2014 and there was no credit available from commercial banks. As a result, we consider that all the sources of credit in the study area are related to contracts, so the perceived credit uncertainty has little likelihood of influencing the farmers' technical itinerary and, subsequently, outcomes from an impact pathway other than contracts.

The distance from a rice miller offering a production contract influences participation in this contract because both farmers and rice millers prefer to undertake a contract with partners that are geographically close. We also consider that this distance has little probability of affecting producers' outcomes, not considering the effect of the contract. Indeed, it is not an indicator of farm isolation, which could influence farmers' access to inputs, advisory centers, paddy markets or food markets, or an indicator of differences between agro-ecological areas. As shown in Fig. 2, there are two tarmacked roads in the *département*, and the distance to these roads is the main indicator of farm isolation rather than the distance between farms and rice millers offering production contracts. These millers are located in the North, around the city of Rosso-Senegal. As a result, some farms located a certain distance from these rice millers are close to tarmacked roads while others located the same distance from the rice millers can be found much further from tarmacked roads. Furthermore, surveyed farms are in the same agro-ecological environment, which is the irrigated part of the *département*.

Nevertheless, the exclusion-restriction condition cannot be tested, so the choice of the instruments and the ability of the models to correct selection bias might be subject to debate. For instance, one could argue that the "perception of credit uncertainty" instrument does not perfectly correct reverse causality because of its design. Although we consider that this bias is limited because contracts were a recent development at the time of the survey, there is no test to prove it.

3.7. Stakeholder validation of impact pathways

The results of the econometric models were discussed with VC stakeholders. Five focus group discussions were held in March 2016, each of which brought together between 7 and 25 participants. They were organized at farmer and national development agency levels. They confirmed the results and enabled the identification of certain impact pathways.

4. Results and discussion

We used t tests to compare the characteristics of treated and control groups (Table 2). The OLS (Table 3) and probit (Table 4) models highlighted the drivers of participation in contracts. Overlap charts are shown in Appendix 1 and tables balancing covariates in Appendix 2. Impacts estimated by IV and PSM models are presented in Table 5. Full IV models are presented in Appendix 3. The robustness of the PSM models tested with Rosenbaum bounds tests is in Appendix 4.

4.1. Descriptive statistics of contract and non-contract households

Table 2 shows a number of differences between farms with a

Table 2
Mean comparison of producer characteristics.

	Producers who sold through spot transactions N = 141		Producers who did not grow rice N = 44		Producers with a marketing contract N = 130			Producers with a production contract N = 155			
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	t-value (comparison with producers who sold through spot transactions)	Mean	Standard deviation	t-value (comparison with producers who sold through spot transactions)	t-value (comparison with producers who did not grow rice)
Livelihoods											
Developed area (ha)	1.29	1.15	1.61	1.66	1.54	.98	−1.88**	2.71	2.58	−5.99***	−2.64***
Number of active members	2.29	.99	3.25	1.92	3.15	1.36	−5.94***	4.16	1.93	−10.31***	−2.73***
Experience in rice growing (years)	18.05	10.03	21.35	13.31	19.08	7.66	−.94	18.24	8.79	−.17	1.81**
Age of head of household (years)	47.63	11.64	51.04	11.67	49.76	10.54	−1.57*	48.44	10.71	−.62	1.38*
Value of non-land assets in 2010 (FCFA)	1,112,316	1,578,323	3,112,093	1.03e + 07	1,294,650	2,577,529	−.71	1,838,887	2,428,079	−3.02***	1.41*
Dependency ratio (%)	.69	.14	0.59	0.19	.67	.16	.97	.57	.21	5.68***	0.69
Female head of household (dummy)	.16	.36	0.05	0.03	.02	.12	4.19***	.02	.14	4.34***	1
Wolof ethnic group (dummy)	.58	.49	0.74	0.44	.76	.43	3.19***	.64	.48	−1.12	1.22
Outside storage in 2010 (dummy)	.29	.04	0	0	.18	.39	2.05**	.19	.39	2.1**	−3.17***
Degree of farm specialization (%)	.68	.27	0.74	0.19	.64	.26	1.47*	.71	.25	−.69	0.79
Number of members in the producer organization	38.5	57.66	36.09	32.92	40.37	27.19	−.34	20.04	27.56	3.56***	3.26***
Perceived credit uncertainty	.63	.62	3.07	1.34	1.18	.56	−7.52***	1.09	.54	−6.78***	14.74***
Ownership of vehicle in 2010 (dummy)	.56	.5	0.67	0.47	.64	.48	−1.44*	.67	.47	−1.96**	0.04
Distance from miller offering a production contract (km)	43.01	22.45	37.81	26.09	30.89	13.44	5.34***	28.12	12.82	7.08***	3.39***
Rice growing financed by CNCAS (dummy)	1	0	0	0	1	0	.	.026	.11	103.51***	−0.76
Marketing											
Share of producers combining contract and spot	0	0	.	.	0.8846	.3207	–32.75***	0.9871	.1132	−97.05***	.
Share sold under contract	0	0	.	.	.7	.17	−68.11***	.67	.16	−69.27***	.
Share sold through spot transaction	1	0	.	.	.30	.17	68.11***	.33	.16	69.27***	.
Performance											
Profit per kilogram contract	44.57	21.12	0	0	44.74	19.6	−.07	24.26	21.04	8.28***	−7.64***
Profit per kilogram total	44.57	21.12	0	0	44.94	19.97	−.15	29.22	22.35	6.06***	−8.66***
Price of sales contract	128.35	9.27	0	0	126.25	7.68	2.02**	103.88	4.37	29.46***	−1.6e + 02***
Price of sales total	128.35	9.27	0	0	126.46	9.16	1.68**	108.84	6.01	21.67***	−1.2e + 02***
Yield (kg)	6713.6	1381.6	0	0	6.487	1.772	1.21	6.822	1.516	−.64	−29.79***
Production cost per kilogram	83.78	19.27	0	0	81.51	18.94	.98	79.61	20.26	1.81***	−26.01***
HFIAS total	6.72	5.28	6.32	6.27	4.02	3.75	4.82***	4.23	4.19	4.53***	2.55***
HFIAS quantity	1.08	2.94	2.18	3.84	.18	.62	3.39***	.63	1.49	1.69**	4.08***
HFIAS quality	4.78	3.33	3.14	2.67	3.14	3.38	4.02***	2.79	2.45	5.88***	0.8

"." means there is no value because these producers did not grow rice.

Table 3
First-stage regression of instrumental variable models.

Control group	Marketing contract			Production contract					
	Producers who used a CNCAS loan and sold through spot transactions			Producers who had no CNCAS loan and did not grow rice			Producers who used a CNCAS loan and sold through spot transactions		
	Coef.	Std. err.	t	Coef.	Std. err.	t	Coef.	Std. err.	t
Perceived credit uncertainty	.1868289	.0464351	4.02***	−.2513846	.016902	−14.87***	.1434112	.0437609	3.28***
Distance from miller offering a production contract (km)	−.0043677	.001542	−2.83***	.0000845	.0018441	0.05	−.0055894	.0015788	−3.54***
Developed area (ha)	−.0439674	.0257504	−1.71*	.0162315	.0070008	2.32**	.0250036	.0116305	2.15**
Number of active members	.1594819	.0293255	5.44***	.0039542	.0149315	0.26	.1067921	.0191339	5.58***
Experience in rice growing (years)	−.004338	.0033935	−1.28	−.0046857	.0032037	−1.46	−.0071135	.0037325	−1.91*
Age of head of household (years)	−.0023125	.0027244	−0.85	.0019601	.0025788	0.76	−.0009686	.0026481	−0.37
Value of non-land assets in 2010 (FCFA)	6.94e−09	1.26e−08	0.55	−2.21e−09	1.67e−09	−1.32	1.20e−08	1.11e−08	1.09
Dependency ratio (%)	.4175219	.229695	1.82*	.1019829	.1388903	0.73	−.0387221	.1825998	−0.21
Female head of household (dummy)	−.4075276	.1037462	−3.93***	−.0674759	.0983552	−0.69	−.2361236	.1002387	−2.36**
Wolof ethnic group (dummy)	.0839773	.0586572	1.43	−.03067	.0442172	−0.69	.0328406	.0474365	0.69
Outside storage in 2010 (dummy)	−.0060384	.0710092	−0.09	.1302446	.044005	2.96***	−.0067104	.0538639	−0.12
Degree of farm specialization	−.0282798	.1023969	−0.28	−.0262245	.0935345	−0.28	.2589675	.0916424	2.83***
Number of members in the producer organization	.0012619	.0006403	1.97**	.0001306	.0011124	0.12	.0000826	.0005064	0.16
Ownership of vehicle in 2010 (dummy)	.0557671	.0553397	1.01	−.0160055	.045018	−0.36	.0872611	.0509061	1.71*
Constant	−.0760453	.2489585	−0.31	1.074516	.1689925	6.36***	.1420606	.2053191	0.69
Prob > F	0.0000			0.0000			0.0000		
Adj R-squared	0.3107			0.5220			0.4400		
Number of observations	271			198			296		

Table 4
Probit models of participation in marketing and production contracts.

Control group	Marketing contract		Production contract			
	Producers who used a CNCAS loan and sold through spot transactions		Producers who had no CNCAS loan and did not grow rice[a]		Producers who used a CNCAS loan and sold through spot transactions	
	Coef.	Std. err.	Coef.	Std. err.	Coef.	Std. err.
Perceived credit uncertainty	.6236314***	.1631955	−1.295788***	.2258637	.5080035***	.1625587
Distance from miller offering a production contract (km)	−.0145715***	.0055171	.0055066	.0132327	−.020091***	.0056712
Developed area (ha)	−.1277283	.0852572	.1424161	.0968281	.113973**	.0569132
Number of active members	.5421756***	.1114392	−.156604	.1297812	.4112823***	.0811513
Experience in rice growing (years)	−.0164054	.0111671	−.0211914	.018288	−.01982*	.0114519
Age of head of household (years)	−.0058191	.0098015	.0158517	.018801	−.0058388	.0104103
Value of non-land assets in 2010 (FCFA)	3.15e−08	4.06e−08	−7.22e−08	6.57e−08	3.13e−08	4.65e−08
Dependency ratio (%)	1.434883*	.819641	.0414782	1.004712	.1175581	.6299728
Female head of household (dummy)	−2.027782***	.532322	−.6574673	1.334348	−.9163607**	.3967871
Wolof ethnic group (dummy)	.2586531	.2103199	−.426153	.3585172	.0803509	.2020467
Outside storage in 2010 (dummy)	.0024852	.2757133			−.0374356	.2407258
Degree of farm specialization	−.1317255	.3495921	−.0763815	.6824843	.836297**	.3687557
Number of members in the producer organization	.0060427**	.0027263	−.0041944	.0076807	−.0011935	.0033605
Ownership of vehicle in 2010 (dummy)	.2146745	.1953337	−.2441487	.3750272	.3597064*	.2006713
Constant	−2.147944**	.9070439	3.399446***	1.350142	−1.440202**	.7280846
LR chi2	114.80		103.90		163.12	
Prob > chi2	0.0000		0.0000		0.0000	
Pseudo R^2	0.3059		0.5420		0.3982	
Percentage of correct prediction	74.54%		91.72%		80.07%	
N	271		198		296	

Significant levels indicated as *p < .1; **p < .05; ***p < .01.
a: Outside storage is not included in the production contract model with a control group of producers not growing rice because it perfectly predicts success.

Table 5
Results of model assessment of the impacts of marketing and production contracts on the income and food insecurity of small-scale producers.

	Control group	Indicators		Instrumental variable models		Propensity Score Matching Nearest Neighbor Matching	
				Coef.	z-value	ATT	T-stat
Marketing contract	Producers who used a CNCAS loan and sold through spot transactions	Contract only	Profit (FCFA/kg)	−13.61	−1.63	1.74	0.43
			Selling price (FCFA/kg)	−0.83	−0.45	2.74	1.61
		Contract plus spot	Profit (FCFA/kg)	−10.23	−1.21	1.97	0.49
			Selling price (FCFA/kg)	−1.71	−0.87	2.97	1.70*
		Production	Yield (kg/ha)	−1564	−1.25	−112	−0.41
			Production cost (FCFA/kg)	4.91	0.60	1	0.27
		Food insecurity	HFIAS total	−9.83	−3.83***	−1.33	−1.65*
			HFIAS quantity	−5.98	−3.58***	−.68	−1.83*
			HFIAS quality	−7.90	−1.61	−.37	−0.66
Production contract	Producers who had no CNCAS loan and did not grow rice	Contract only	Profit (FCFA/kg)	29.68	7.91***	26.51	13.29***
			Selling price (FCFA/kg)	104.8	100.57***	104.17	292.54***
		Contract plus spot	Profit (FCFA/kg)	34.26	8.61***	31.10	14.57***
			Selling price (FCFA/kg)	109.38	85.78***	108.75	191.01***
		Production	Yield (kg/ha)	6833	29.13***	6994	45.84***
			Production cost (FCFA/kg)	75.12	21.38***	77.66	40.31***
		Food insecurity	HFIAS total	86.01	−3.85***	−2.36	−2.49***
			HFIAS quantity	−6.29	−3.82***	−0.39	−1.70*
			HFIAS quality	−1.87	−2.22**	−1.38	−1.95*
	Producers who used a CNCAS loan and sold through spot transactions	Contract only	Profit (FCFA/kg)	−35.14	−3.93***	−15.63	−3.13***
			Selling price (FCFA/kg)	−36.65	−7.92***	−17.26	−8.53***
		Contract plus spot	Profit (FCFA/kg)	−27.81	−3.09***	−10.63	−2.11**
			Selling price (FCFA/kg)	−29.31	−6.40***	−12.27	−5.97***
		Production	Yield (kg/ha)	−416	−0.67	311.2	1.04
			Production cost (FCFA/kg)	−1.50	−0.20	−1.63	−0.37
		Food insecurity	HFIAS total	−3.15	−1.94*	−.30	−0.31
			HFIAS quantity	1.56	0.37	−.13	−0.32
			HFIAS quality	−2.36	−2.42**	−.19	−0.29

Significant levels indicated as *p < .1; **p < .05; ***p < .01.

contract and those without, particularly in terms of land, number of active members, gender, specialization, access to credit, access to storage, distance from rice millers, number of members in the producer organization and perceived credit uncertainty.

Producers engaged in production contracts or who did not grow rice in the 2014 dry season were not financed by the CNCAS. In contrast, having a bank credit was a prerequisite for participation in marketing contract. Perceived credit uncertainty differed between farms having adopted a marketing contract (1.18) and those financed by CNCAS and marketing through spot transactions (0.63). Similarly, farmers who did not grow rice perceived a higher level of credit uncertainty (3.07) than those adopting production contracts (1.09). Farms with production contracts were closer (28.12 km) to the millers offering this kind of agreement than both those funded by CNCAS and marketing only through spot transactions (43.01 km) and those who did not grow rice in the 2014 dry season (37.81 km).

Farms in the control group funded by CNCAS sold 100% of their paddy through spot transactions. Farms with contracts combined two types of sale. The proportion of farms with contracts that also sold through spot transactions was 88.46% for those with marketing contracts and 98.71% for those with production contracts. The proportion of the volume of paddy sold through spot transactions in the total volume of paddy sold was 30% for farms with a marketing contract and 33% for farms with a production contract.

The total profit per kilogram made by farms with a marketing contract (FCFA 44.94) was similar to that made by the control group of farms growing rice (FCFA 44.57). Farms with production contracts made less profit (FCFA 29.22). Naturally, farms that did not grow rice in the 2014 dry season did not generate any yield, costs or income related to paddy. Farms with a contract had a lower HFIAS score (4.02 in the group with a marketing contract and 4.23 in the group with a production contract) than farms in the control groups (6.72 in the group of farms funded by the bank and 6.32 in the non-rice-growing group).

4.2. Factors influencing participation

The size of the developed surface positively influenced participation in production contracts, except in the case of the probit model for the control group comprising producers not growing rice. The size of producer organizations positively influenced participation in marketing contracts. There is no selection based on farmers' wealth, but the number of active members positively influenced participation in both types of contract, except production contracts with the control group comprising producers not growing rice. Interestingly, experience negatively influences participation in production contracts when the control group consists of rice-growing producers. One miller reported the difficulty encountered in modifying the agricultural practices of certain experienced farmers. The models found a positive influence of farmers' use of storage facilities on participation in production contracts with the control group of farmers not growing rice. The distance from rice millers offering production contracts had a negative influence on participation in such contracts when the control group conducted spot transactions.

Perceived credit uncertainty had a positive influence on participation in both marketing contracts and production contracts for the control group of producers growing rice. These two types of contract may be perceived as securing access to credit. Farm specialization also influenced participation in production contracts when the control group grew rice. Female heads reduced participation in contracts while an increase in the age of the household head and membership of the major ethnic group had no influence.

Matching performed well in the case of marketing contracts (97.69% of treated observations found a match) and production contracts with the control group of producers who did not grow rice (70.5% of treated observations found a match). In the case of production contracts with the control group of producers funded by the bank, the matching reduced less bias. Nevertheless, 89.03% of treated

Table 6
Impact of contracts on agricultural practices.

	Indicators of agricultural practices	Control	Treated	T-stat
Marketing contract	Certified seeds (%)	.98	.96	−0.58
	Quantity of seeds (kg/ha)	128.3	129.9	0.30
	Cost of weeding (FCFA/ha)	26,333	23,942	−1.16
	Quantity of chemical fertilizer 18/46 (kg/ha)	109	105.5	−0.66
	Quantity of chemical fertilizer urea (kg/ha)	276.5	305	1.87*
	Mechanized harvest (%)	0.01	0.00	−0.50
Production contract	Certified seeds (%)	0	.96.6	50.80***
(Control group comprises producers who have no	Quantity of seeds (kg/ha)	0	130.25	41.16***
CNCAS loan and do not grow rice)	Cost of weeding (FCFA/ha)	0	26,921	26.88***
	Quantity of chemical fertilizer 18/46 (kg/ha)	0	104.2	28.57***
	Quantity of chemical fertilizer urea (kg/ha)	0	293.3	62.79***
	Mechanized harvest (%)	0	.033	1.75*
Production contract	Certified seeds (%)	.99	.95	−1.29
(Control group comprises producers who use a	Quantity of seeds (kg/ha)	126	132	1.03
CNCAS loan and sell through spot transactions)	Cost of weeding (FCFA/ha)	23,553	25,518	0.84
	Quantity of chemical fertilizer 18/46 (kg/ha)	102	99.5	−0.32
	Quantity of chemical fertilizer urea (kg/ha)	263.5	294.5	1.59
	Mechanized harvest (%)	.02	.03	0.5

The table presents the differences in agricultural practices between the treated and control groups, evaluated with the nearest neighbor matching algorithm. Significant *t*-test results are indicated as $^{*}p < .1$; $^{**}p < .05$; $^{***}p < .01$.

observations found a match, the absolute standardized differences of means after matching was 17.4%, which is deemed to be good because it is under 25% (Stuart, 2010), and the results of the IV models were similar to the results of the PSM.

4.3. Impact of contracts

4.3.1. Marketing contract

Marketing contracts had no impact on income because yields, production costs and selling prices were the same as in spot transactions. Yields and production costs were similar because the technical itinerary was the same in both groups. Agricultural practices were intensive (Table 6): 98% of producers used certified seed and the average quantity of seed was the same in both groups (128.3 kg/ha). They also used the same quantity of the fertilizer 18–46 (109 kg/ha) and spent the same amount on chemical weeding (FCFA 26.333/ha). Contracted farms used slightly more urea (305 kg/ha) than control farms (276.5 kg/ha) but this did not make any difference in yields. This was validated during focus group discussions.

Second, there was no premium because producers sold paddy of the same quality under a contract and through spot transactions. Indeed, 98% of producers in both groups grew only one variety (Sahel 108). Furthermore, 64.44% of members of producer organizations grew the same variety and 32.22% grew two varieties that were stored separately. Finally, the storage conditions (which influence the moisture content) were the same whether the paddy was sold under a marketing contract or through spot transactions, with 88.65% of producers using collective storage for the sale used to repay the credit ($t = -1.02$). This means the price per kilogram was the same for marketing contracts and spot transactions.

This result differed from the literature on contract farming which reports an upgrading of processes and products (Gow and Swinnen, 1998; Reardon et al., 2009). We considered a marketing contract the aim of which was to influence repayment of a loan and improve the quality of paddy, but not to intensify agricultural practices. Furthermore, intensification of rice growing in the Senegal River valley started in 1973 and there had been no major changes in inputs since (Le Gal, 1995). The content of the marketing contract in our study thus differed from the contracts usually addressed by the literature on contract farming.

Marketing contracts were shown to reduce producer food insecurity (by 9.83 points) through the quantitative dimension of the HFIAS indicator (5.98 points). This result was robust ($z = -3.83$ and $z = -3.58$ respectively). Tobit models found a stronger impact than PSM because they did not take the zero-values into consideration. Focus group discussions highlighted the fact that the impact was due to the mitigation of price seasonality. Indeed, the minimum price of a marketing contract was FCFA 112.5 per kg in July and the maximum price was FCFA 137.5 per kilogram in December. The price of spot transactions ranged from FCFA 83.35 per kilogram to FCFA 150 per kg over the same period. The CNCAS loan was repaid by 83.03% of producers between August and October, when the price obtained through spot transactions was lower than that obtained with a marketing contract. This means that with a marketing contract, producers supplied less paddy to repay the same amount of loan as when they sold the rice through a spot transaction. This enabled them to stock more paddy for home consumption and other uses. The positive impact of contract farming on farmers' food security was also reported in the literature (Bellemare and Novak, 2017).

Models and focus groups did not highlight the fact that the marketing contract increased the competition between sales to repay the loan and household food consumption. Indeed, producers engaged in spot transactions also faced this competition because the loan is repaid collectively.

4.3.2. Production contract

First, we compared the performance of producers having adopted a production contract with the performance of producers who did not grow rice because they could not afford to. The control group comprised rice growers who owed money to the CNCAS during the 2014 dry season and who thus could not take out a loan. Models yielded results that are intuitive because the performance of the control group in terms of yield, costs, price and profit was zero.

Production contracts had a positive impact on producers' incomes and a negative impact on producers' food insecurity. Yields reached 6833 kg per hectare and the cost per kilogram of paddy produced was FCFA 75.12. The profit per kilogram was FCFA 29.68 for sales conducted by contract and increased to FCFA 34.26 when we added spot

transactions. Food insecurity was reduced by 6.01 points. These results were robust to omitted variable (z = 7.91 and gamma = 6.7 for profit, and z = 100.57 and gamma = 17.7 for selling price). They were in line with the literature on contract farming which reports an increase in farmers' income through access to inputs on credit (Reardon et al., 2009). Focus group discussions confirmed that farmers opt for production contracts to obtain a loan.

Second, we compared the performance of producers having adopted a production contract with the performance of producers benefitting from a CNCAS loan who sold their rice through spot transactions. We found a negative impact on income.

The negative impact of production contracts on the profit per kilogram varied depending on the model, representing either FCFA 35.14 or FCFA 15.63. The result was robust (z-value = −3.93 and gamma = 4.8). This impact was not explained by differences in yields and production costs because there was no difference in agricultural practices (Table 6). Rice millers who offered production contracts provided inputs and technical support that were similar to those provided by SAED. Producers in both groups used the same quantities of certified seed (126 kg/ha), fertilizers (102 kg/ha for 18/46 and 263.5 kg/ha for urea) and spent the same amount on chemical weeding (FCFA 23,553/ha).

The difference in profits was explained by a lower selling price (FCFA 36.65/kg or FCFA 17.26/kg depending on the model). The result was robust (z-value = −7.92 and gamma = 27) and was confirmed during focus group discussions. The lower selling price was not due to lower quality, because the same farmers sold the same quality of paddy (Sahel 108) at FCFA 103.88/kg with a production contract and at FCFA 119.09/kg through spot transactions.

The lower selling price observed under a production contract was due to the inclusion of implicit interest and insurance costs. First, the oligopolistic structure of the credit market in which producer organizations excluded from the national bank participate favored higher interest rates. Farms in the sample are specialized (an average of 69.08% of their income came from paddy) and the high cost of growing rice (FCFA 509,157 per hectare) required the use of external funding. A production contract was often the only option for producers excluded from the national bank since tied input-output relationships were limited in the area (these concerned only 0.91% of producers). Only three millers offered a production contract in 2014, and this segment of the market was not regulated either by the state or by the inter-professional organization. It favored high rates of interest set by millers operating in an oligopolistic market.

Second, producers who had been excluded from CNCAS loans represented a high risk of non-repayment for millers who offered production contracts. In the 2014 dry season, the three millers reported rates of repayment ranging from 70% to 90% of the total amount lent. To make up for their losses, millers included an implicit insurance cost. If a producer did not repay the rice miller, a new contract could be set up the following season with stricter surveillance to be sure the producer would repay the previous credit and the new one. Technicians visited the plot more often and obtained power of decision over the main technical steps (sowing, use of chemical inputs, irrigation and harvesting). The insurance cost was used to fund this closer surveillance. It could also cover part of the losses when there was no possibility of taking out a new contract.

Production contracts were used as a funding mechanism by producers excluded from the national bank. This contract included interest and insurance costs linked to the loan that reduced their income. That is why none of the producers sold more paddy through production contracts than the volumes corresponding to the value of the credit. We could not distinguish the respective share of the interest from the implicit insurance costs. The production contract did not increase yields or the quality of the product, and therefore did not increase the selling price.

Finally, the difference in profit per kilogram was reduced by 20.86% when we included spot transactions undertaken by producers with a production contract (z-value = −3.09 and gamma = 13.4). This was due to the reduction in the difference in the selling price. Undertaking spot transactions combined with a production contract thus increased the producers' average profit.

5. Conclusion and policy implications

Most of the literature reports that contract farming in export VCs of high value products favors access by small-scale producers to improved inputs, technical advisory services and remunerative markets (Reardon et al., 2009). However, much less information is available about the impacts of the contracts emerging in domestic grain chains in Africa. In this paper, we tested the hypotheses that contracts in domestic grain chains improve farmers' incomes and reduce food insecurity. The case selected is the rice VC in the Senegal River valley, where policies support the implementation of marketing contracts and millers offer production contracts. We used instrumental variables and propensity score matching models to correct selection bias on a dataset of 470 observations.

We found that marketing contracts had no impact on producers' incomes. The technical itinerary used by producers with a marketing contract was the same as that used by producers with a loan from the national bank who sold their paddy through spot transactions because they were both promoted by the national agricultural agency. Furthermore, there was no premium because the quality of paddy sold by producers with a marketing contract and through spot transactions was the same. As a result, a marketing contract did not lead to an upgrading of producers. It was an organizational device that ensured that producers repaid their loans and that millers received supplies. It nevertheless decreased producers' food insecurity because it mitigated price seasonality. Producers sold their paddy to repay their loan during the two months following the harvest, when the price under marketing contracts was higher than the spot market price.

Production contracts had a positive impact on the income of producers who had no access to credit from the national bank because they represented the only recourse they had to fund rice growing. Nevertheless, the income of producers with a production contract was lower than the income of producers funded by the bank and marketing through spot transactions. A production contract included implicit interest and insurance costs that represented the costs of the loss of access to credit at the national bank. Finally, by combining a production contract and spot transactions, producers increased their profit.

Rural credit markets in developing countries are often characterized by imperfect information and weak enforcement of repayment by legal institutions (Hoff and Stiglitz, 1993). For these reasons, commercial banks do not often offer credit to small-scale producers and many debt forgiveness programs have been implemented for public agricultural banks. Informal institutions may have a competitive advantage in reducing transaction costs (Besley, 1994). Lenders specialize in certain types of borrowers and the credit market becomes segmented. That is what happened in the Senegal River Valley. The first segment concerns credit from the national bank. Marketing contracts were created to secure repayment. The interest rate is low because the credit policy supports agricultural development with subsidies. The second segment concerns credit through a production contract. This resembles an informal credit arrangement because screening, monitoring and enforcement are rooted in geographical and relational proximity.

Nevertheless, production contracts are drafted with explicit accountability and include complex indicators of quality. They involve high interest and insurance rates because transaction costs are high and the structure of this credit segment is oligopolistic. Producer organizations excluded from the national bank resort to this type of contract because it is the last chance they have to fund rice (Besley, 1994).

The observations made in the Senegal River Valley provide insights for policies supporting the modernization of domestic grain chains in West Africa. First, the development of credit insurance systems, which were introduced by CNCAS in the Senegal River Valley, could prevent producer organizations unable to repay loans from being excluded by the formal banks and from turning to less profitable funding agreements. However, the development of insurance systems for agricultural credit in Africa faces the challenges of adverse selection and moral hazards. Research is needed to understand the drivers of loan defaults by producers, particularly the variety of shocks they face as well as possible opportunistic behavior. Second, the existence of an incentive price would support the modernization of value chains. In Senegal, in a context of strong competition for paddy purchase, a price paid by processors that is higher than that of spot transactions would secure their supplies. Inter-professional associations should be supported by public services in order to facilitate the negotiation of contract prices between producers and processors. In the Senegal River Valley, an indicative price for marketing contracts is successfully negotiated within the inter-professional association. Negotiations should also take particular account of the breakdown of the interest and insurance rates applied in the production contracts, the leverage point of farmers being strong competition in processors' paddy purchases.

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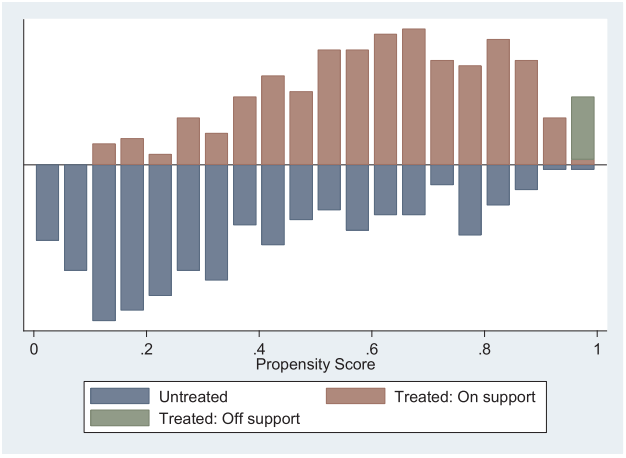
Appendix 1. Common support: Histogram of the estimated propensity score for treated and control groups

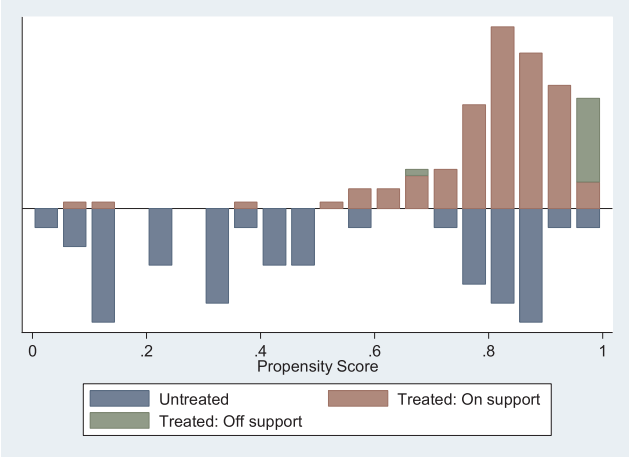
Marketing contract

The control group comprises producers who used a CNCAS loan and sold through spot transactions

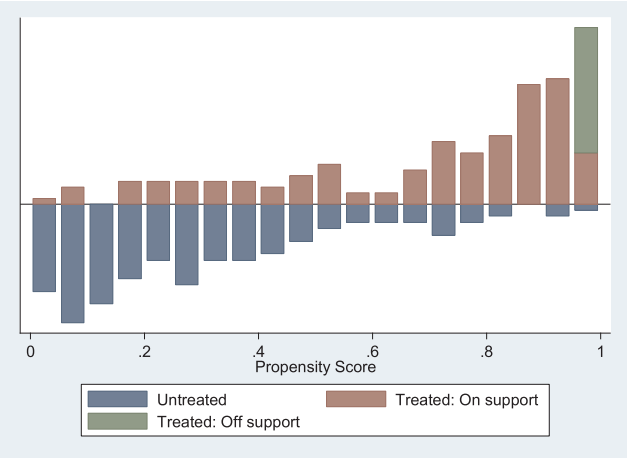


Production contract

The control group comprises producers who had no CNCAS loan and did not grow rice



Production contract
The control group comprises producers who used a CNCAS loan and sold through spot transactions



Appendix 2. Balancing of covariates before and after matching according to treatments

Marketing contract (the control group comprises producers who used a CNCAS loan and sold through spot transactions)

Sample		Mean		%bias	% bias reduction	*t*-test		V(T)/V(C)
		Treated	Control			t	p > t	
Developed area	Unmatched	1.5393	1.2938	22.9		1.88	0.061	0.72
	Matched	1.5614	1.5228	3.6	84.3	0.30	0.761	0.88
Number of active members	Unmatched	3.1462	2.2908	71.8		5.94	0.000	1.86*
	Matched	3.0945	2.9449	12.6	82.5	0.96	0.340	1.29
Experience in rice growing	Unmatched	19.077	18.05	11.5		0.94	0.347	0.58*
	Matched	19.079	19.494	−4.7	59.5	−0.34	0.731	0.48*
Age of head of household	Unmatched	49.762	47.631	19.2		1.57	0.117	0.82
	Matched	49.945	49.282	6.0	68.9	0.48	0.629	0.88
Value of non-land assets in 2010	Unmatched	1.3e + 06	1.1e + 06	8.5		0.71	0.479	2.67*
	Matched	1.3e + 06	1.3e + 06	−0.9	89.5	−0.07	0.944	2.54*
Dependency ratio	Unmatched	.67146	.68937	−11.7		−0.97	0.334	1.29
	Matched	.6742	.68171	−4.9	58.1	−0.40	0.689	1.48*
Female head of household	Unmatched	.01538	.15603	−51.7		−4.19	0.000	.
	Matched	.01575	.02992	−5.2	89.9	−0.75	0.452	.
Wolof ethnic group	Unmatched	.76154	.58156	38.9		3.19	0.002	.
	Matched	.76378	.74331	4.4	88.6	0.38	0.706	.
Outside storage in 2010	Unmatched	.18462	.29078	−25.0		−2.05	0.041	.
	Matched	.18898	.11811	16.7	33.2	1.57	0.118	.
Degree of farm specialization	Unmatched	.63814	.68541	−18.0		−1.48	0.141	0.90
	Matched	.6366	.61639	7.7	57.2	0.59	0.558	0.74
Number of members in the producer organization	Unmatched	40.369	38.499	4.1		0.34	0.736	0.22*
	Matched	40.197	43.789	−8.0	−92.0	−0.93	0.351	0.60*
Ownership of vehicle in 2010	Unmatched	.64615	.56028	17.6		1.44	0.150	.
	Matched	.6378	.52598	22.9	−30.2	1.81	0.071	.
Distance from miller offering a production contract	Unmatched	30.896	43.014	−65.5		−5.34	0.000	0.36*
	Matched	31.091	25.563	29.9	54.4	2.63	0.009	0.48*
Perceived credit uncertainty	Unmatched	1.1769	.63121	91.7		7.52	0.000	0.81
	Matched	1.1732	1.1654	1.3	98.6	0.11	0.913	0.96

"." : Variance ratios are provided for continuous variables only

Production contract (the control group comprises producers who had no CNCAS loan and did not grow rice)

Sample		Mean		%bias	% bias reduction	*t*-test		V(T)/V(C)
		Treated	Control			t	p > t	
Developed area	Unmatched	2.7687	1.6112	51.7		2.65	0.009	2.60*
	Matched	2.2908	2.2355	2.5	95.2	−0.22	0.829	2.05*

Number of active members	Unmatched	4.1825	3.2558	47.5		2.67	0.008	1.07
	Matched	4.6222	4.7856	−8.4	82.4	−0.56	0.578	0.95
Experience in rice growing	Unmatched	18.325	21.349	−26.9		−1.70	0.092	0.43*
	Matched	19.3	20.819	−13.5	49.8	−0.96	0.337	0.48*
Age of head of household	Unmatched	48.905	51.047	−19.2		−1.11	0.267	0.82
	Matched	49.444	50.254	−7.3	62.2	−0.48	0.633	0.68
Value of non-land assets in 2010	Unmatched	1.8e + 06	3.1e + 06	−17.2		−1.31	0.191	0.05*
	Matched	1.9e + 06	2.5e + 06	−7.1	58.6	−1.64	0.102	1.79*
Dependency ratio	Unmatched	.55472	.59521	−20.2		−1.11	0.268	1.29
	Matched	.53608	.53989	−1.9	90.6	−0.14	0.886	2.33*
Female head of household	Unmatched	.01587	.04651	−17.5		−1.14	0.256	.
	Matched	.01111	0	6.4	63.7	1.00	0.319	.
Wolof ethnic group	Unmatched	.61905	.74419	−26.9		−1.49	0.139	.
	Matched	.67778	.62389	11.6	56.9	0.76	0.451	.
Outside storage in 2010	Unmatched							
	Matched							
Degree of farm specialization	Unmatched	.69581	.73963	−19.7		−1.05	0.294	1.63*
	Matched	.69854	.67135	12.2	37.9	0.72	0.475	0.85
Number of members in the producer organization	Unmatched	20.087	36.93	−55.0		−3.24	0.001	0.74
	Matched	21.878	31.891	–32.7	40.5	−2.33	0.021	0.86
Ownership of vehicle in 2010	Unmatched	.65079	.67442	−5.0		−0.28	0.780	.
	Matched	.73333	.82944	−20.2	−306.8	−1.56	0.120	.
Distance from miller offering a production contract	Unmatched	27.004	37.814	−52.4		−3.54	0.001	2.60*
	Matched	28.333	28.046	1.4	97.3	0.13	0.894	2.05*
Perceived credit uncertainty	Unmatched	1.0873	3.0698	−193.4		−13.78	0.000	1.07
	Matched	1.2333	1.1111	11.9	93.8	2.11	0.037	0.95

"." : Variance ratios are provided for continuous variables only
Outside storage is not included because it perfectly predicts success

Production contract (the control group comprises producers who used a CNCAS loan and sold through spot transactions)

Sample		Mean		%bias	% bias reduction	*t*-test		V(T)/V(C)
		Treated	Control			t	p > t	
Developed area	Unmatched	2.7106	1.2938	70.9		6.00	0.000	4.98*
	Matched	2.2713	2.6134	−17.1	75.9	−1.45	0.147	0.82
Number of active members	Unmatched	4.1613	2.2908	121.7		10.31	0.000	3.76*
	Matched	3.8913	3.1623	47.4	61.0	4.08	0.000	2.33*
Experience in rice growing	Unmatched	18.239	18.05	2.0		0.17	0.863	0.77
	Matched	17.949	17.92	0.3	84.7	0.02	0.983	0.38*
Age of head of household	Unmatched	48.445	47.631	7.3		0.63	0.532	0.85
	Matched	48.754	49.164	−3.7	49.6	−0.29	0.773	0.73
Value of non-land assets in 2010	Unmatched	1.8e + 06	1.1e + 06	35.5		3.02	0.003	2.37*
	Matched	1.8e + 06	2.0e + 06	−9.5	73.4	−0.70	0.485	1.19
Dependency ratio	Unmatched	.57125	.68937	−66.7		−5.68	0.000	2.09*
	Matched	.58008	.64748	−38.1	42.9	−2.99	0.003	1.55*
Female head of household	Unmatched	.01935	.15603	−49.6		−4.34	0.000	.
	Matched	.02174	.03188	−3.7	92.6	−0.52	0.603	.
Wolof ethnic group	Unmatched	.64516	.58156	13.0		1.12	0.263	.
	Matched	.65217	.66957	−3.6	72.7	−0.30	0.761	.
Outside storage in 2010	Unmatched	.1871	.29078	−24.4		−2.11	0.036	.
	Matched	.18841	.12899	14.0	42.7	1.35	0.178	.
Degree of farm specialization	Unmatched	.70634	.68541	8.0		0.69	0.491	0.88
	Matched	.706	.7766	−27.0	−237.2	−2.33	0.020	1.05
Number of members in the producer organization	Unmatched	20.045	38.499	−40.8		−3.56	0.000	0.23*
	Matched	21.594	28.123	−14.4	64.6	−2.19	0.029	1.98*
Ownership of vehicle in 2010	Unmatched	.67097	.56028	22.8		1.96	0.050	.
	Matched	.66667	.63188	7.2	68.6	0.60	0.547	.
Distance from miller offering a production contract	Unmatched	28.129	43.014	−81.4		−7.08	0.000	0.33*
	Matched	28.551	22.289	34.3	57.9	3.31	0.001	0.58*
Perceived credit uncertainty	Unmatched	1.0903	.63121	78.6		6.78	0.000	0.74
	Matched	1.058	1.2	−24.3	69.1	−2.25	0.000	0.99

"." : Variance ratios are provided for continuous variables only

Appendix 3. Details for instrumental variable models

Marketing contract (the control group comprises producers who used a CNCAS loan and sold through spot transactions).

	IV-2SLS models						IV-Tobit models		
	Contract only		Contract plus spot		Production		Food insecurity		
	Profit per kilogram	Selling price per kilogram	Profit per kilogram	Selling price per kilogram	Yield (kg)	Production cost per kilogram	HFIAS total	HFIAS quantity	HFIAS quality
Marketing contract	**−13.60741**	**−.8343582**	**−10.22972**	**−1.70716**	**−1564.657**	**4.913894**	**−9.82719*****	**−5.976419*****	**−7.90286**
Developed area	−1.783008	−1.686974***	−1.758716	−1.721722***	−159.8947*	−.01313	−.6888693*	−.6298325***	.0723007
Number of active members	1.447714	−.2000419	.118214	−.691214	273.0324	−.0976898	.8718214	.7244957*	−.9181607
Experience in rice growing	−.1495686	.0470817	−.1209822	.0490429	−24.10916	.1474203	−.0873597*	−.0353957	−.016327
Age of head of household	.2286699*	.0666197	.1594482	−.0093837	−.4665633	−.1745897	−.0321562	−.0421465*	−.0088948
Value of non-land assets in 2010	3.60e−07	−2.71e−08	−2.10e−08	−3.87e−07**	.0001332***	−3.48e−07	1.75e−07	2.42e−07**	2.30e−09
Dependency ratio	2.881517	4.557905	−6.244837	−1.817204	216.1586	6.763433	−5.470698	−2.977214	−17.56577***
Female head of household	−18.14665**	1.344338	−18.11886**	−.8597275	−1273.743**	15.3643**	−2.897292	−2.055836	−.9661224
Wolof ethnic group	3.818301	.7230963	1.236075	−1.325754	516.5046**	−2.108993	1.156161	−.0099149	3.255679*
Outside storage in 2010	3.855751*	11.43705***	4.224283*	11.1593***	−209.3128	6.386323***	2.815057***	3.928481***	−8.680961***
Degree of farm specialization	4.322514	.632954	3.321156	−.7370633	234.3388	−4.371209	.5628526	−.3905818	3.859832*
Number of members in the producer organization	−.0243467	−.0142778*	−.0108193	.0027943	−7.028103***	.016623	.02517***	.0073598	.0270728**
Ownership of vehicle in 2010	−3.017748	.4585731	−3.767786	.0502036	−204.3067	4.108065*	−.6377393	−.6546363	−.4327139
Constant	37.08303***	120.0065***	50.84325***	132.4454***	7069.201***	80.48026***	12.65855***	9.378244***	7.900464
Prob > chi2	0,0046	0.0000	0.0048	0.0000	0.0000	0.0023	0.0000	0.0000	0.0006
Endogeneity test of treatment variable (p-value)	0,0836	0.6221	0.1357	0.0820	0.0341	0.3771			
Over-identification test (Chi-sq(1) P-val)	0.8466	0.7824	0.6048	0.5678	0.2768	0.0894			
Weak identification test (Cragg-Donald Wald F statistic)	14.992								
Under-identification test with Anderson canon. corr. LM statistic	22,593								
Anderson Rubin weak instrument robustness test (p-value)							0.0000	0.0000	0.0789
Number of observations	271								
Instruments	Perceived credit uncertainty and distance to the closest rice miller offering a production contract								

Significant levels indicated as $^{*}p < .1$; $^{**}p < .05$; $^{***}p < .01$

Production contract (the control group comprises producers who had no CNCAS loan and did not grow rice)[a]

	IV-2SLS models						IV-Tobit models		
	Contract only		Contract plus spot		Production		Food insecurity		
	Profit per kilogram	Selling price per kilogram	Profit per kilogram	Selling price per kilogram	Yield (kg)	Production cost per kilogram	HFIAS total	HFIAS quantity	HFIAS quality
Production contract	**29.67745*****	**104.7979*****	**34.26264*****	**109.3831*****	**6833.578*****	**75.12049*****	**−6.00715*****	**−6.286255*****	**−1.869091****
Developed area	−.6901933	−.2481955	−.7514009	−.3094031*	−94.70013**	.4419979	.1625613	.2647594	.0623586
Number of active members	.2794899	.0982483	−.0257517	−.2069935	109.6636*	−.1812416	−.6829447**	−.345121	−.3937716**
Experience in rice growing	.114889	.0291673	.1307326	.045011	10.98971	−.0857217	.1014754*	.09585	.0697321**
Age of head of household	.1403783	.0079824	.1872553	.0548595	−3.62189	−.1323959	−.170995***	−.182501***	−.093796***
Value of non−land assets in 2010	2.72e−08	4.85e−08	3.34e−08	5.47e−08	2.01e−06	2.13e−08	−3.65e−07*	−6.82e−07**	−2.22e−07**
Dependency ratio	7.064511	−.9758276	3.612173	−4.428167	464.4579	−8.040339	.2319892	1.754736	−.6896698
Female head of household	7.674343	5.340848	7.153243	4.819749	373.8842	−2.333495	1.302712	3.234243	.3008453
Wolof ethnic group	1.522076	−.3456873	.9214721	−.9462907	132.8209	−1.867763	.4728563	1.653131	.1526987
Outside storage in 2010	−15.27199***	−2.450925***	−13.37033***	−.5492615	−926.3777***	12.82107***	3.208388**	1.42825	1.80063***
Degree of farm specialization	−7.429016	−1.553956*	−8.292266	−2.417207*	−665.1243	5.875059	3.442621*	1.649093	2.389997**
Number of members in the producer organization	.0047903	−.0302797***	−.0002566	−.0353266**	−1.413456	−.03507	−.0442296**	−.0138461	−.034577***
Ownership of vehicle in 2010	.7368089	−.0991103	.9552457	.1193266	−4.382926	−.8359191	.0980856	−1.36124	.1856119
Constant	−11.10067	1.369629	−9.342226	3.128066	36.32217	12.47029	15.21777***	7.874804**	7.773748***
Prob > chi2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003	0.0000
Endogeneity test of treatment variable (p-value)	0.7511	0.5908	0.6865	0.6519	0.2643	0.7911			
Over-identification test (Chi-sq(1) P-val)	0.3934	0.5505	0.3713	0.9588	0.7531	0.8616			
Under-identification test with Anderson canon. corr. LM statistic	38.859								
Anderson Rubin weak instrument robustness test (p-value)							0.0003	0.0004	0.0758
Number of observations	198								
Instruments	Perceived credit uncertainty								

Significant levels indicated as $^{*}p < .1$; $^{**}p < .05$; $^{***}p < .01$

A: the model is exactly identified so the Sargan-Hansen test cannot be performed

Production contract (the control group comprises producers who used a CNCAS loan and sold through spot transactions)

	IV-2SLS models						IV-Tobit models		
	Contract only		Contract plus spot		Production		Food insecurity		
	Profit per kilogram	Selling price per kilogram	Profit per kilogram	Selling price per kilogram	Yield (kg)	Production cost per kilogram	HFIAS total	HFIAS quantity	HFIAS quality
Production contract	**−35.14347*****	**−36.64611*****	**−27.81194*****	**−29.31458*****	**−416.7062**	**−1.502643**	**−3.151219***	**1.558317**	**−2.360846****
Developed area	−.7039283	−.0644408	−.8345084	−.1950209	−109.3331**	.6394875	.0946185	.5007817*	−.0654904
Number of active members	1.557014	1.387208*	1.052938	.8831326	106.6444	−.1698058	−.4194247	−.6792689	−.2621878
Experience in rice growing	−.0462244	−.0363188	−.011652	−.0017465	4.821192	.0099056	−.0248819	.0761012	−.0142895
Age of head of household	.2359705*	−.0117168	.2650609**	.0173735	2.805359	−.2476874**	−.0921266**	−.119605*	−.060578***
Value of non-land assets in 2010	1.28e−07	4.23e−07*	1.23e−07	4.18e−07*	.000015	2.95e−07	−9.62e−08	−8.77e−07**	2.95e−08
Dependency ratio	−.6473544	−3.527372	−3.536236	−6.416254	167.4664	−2.880018	−5.32822**	−5.399834	−3.351461**
Female head of household	−12.97473	−1.30527	−12.07166	−.402193	−621.2902	11.66946*	2.181841	2.357291	1.272683
Wolof ethnic group	2.232087	−.1111592	1.749858	−.5933885	170.2569	−2.343246	.5765476	3.529816***	−.3698172
Outside storage in 2010	−4.780721*	2.547361**	−3.83012	3.497962***	−346.2228*	7.328083**	2.405036***	−2.27794	2.56955***
Degree of farm specialization	−.4526917	−.2484256	−1.245233	−1.040967	−190.3443	.204266	2.868463**	4.228176*	1.214157
Number of members in the producer organization	−.0411033	−.036664***	−.0397786	−.0353393***	−5.672336***	.0044393	.0065682	.0317675**	−.0080702*
Ownership of vehicle in 2010	−1.255333	−.1527162	−1.272451	−.169834	−104.5116	1.102617	−.8944849	−1.97566*	−.5029641
Constant	41.52727***	134.0275***	42.51444	135.0146***	6902.823***	92.5002***	13.08422***	−.8116921	9.932533***
Prob > chi2	0.0000	0.0000	0.0000	0.0000	0.0026	0.0000	0.0000	0.0005	0.0000
Endogeneity test of treatment variable (p-value)	0.0814	0.0001	0.1400	0.0014	0.4304	0.7714			
Over-identification test (p-val)	0.3206	0.8727	0.3058	0.9420	0.7795	0.2372			
Weak identification test (Cragg-Donald Wald F statistic)					16.024				
Under-identification test with Anderson canon. corr. LM statistic					22.201				
Anderson Rubin weak instrument robustness test (p-value)							0.0057	0.0727	0.0002
Number of observations	296								
Instruments	Perceived credit uncertainty and distance to the closest rice miller offering a production contract								

Significant levels indicated as $^{*}p < .1$; $^{**}p < .05$; $^{***}p < .01$

Appendix 4. Critical values of Rosenbaum bounds test for nearest neighbor matching

Marketing contract	Control group comprises producers who used a CNCAS loan and sold through spot transactions	Contract only	Profit per kilogram	
			Selling price per kilogram	
		Contract and spot	Profit per kilogram	
			Selling price per kilogram	1.25**
		Production	Yield (kg)	
			Production cost per kilogram	
		Food insecurity	HFIAS total	1.48**
			HFIAS quantity	5.0*
			HFIAS quality	
Production contract	Control group comprises producers who had no CNCAS loan and did not grow rice	Contract only	Profit per kilogram	6.7**
			Selling price per kilogram	17.7***
		Contract and spot	Profit per kilogram	6.9**
			Selling price per kilogram	16.7***
		Production	Yield (kg)	16.6**
			Production cost per kilogram	17.1**
		Food insecurity	HFIAS total	2.3**
			HFIAS quantity	1.0**
			HFIAS quality	2.1**
	Control group comprises producers who used a CNCAS loan and sold through spot transactions	Contract only	Profit per kilogram	4.8**
			Selling price per kilogram	27**
		Contract and spot	Profit per kilogram	1.7**
			Selling price per kilogram	13.4**
		Production	Yield (kg)	
			Production cost per kilogram	
		Food insecurity	HFIAS total	
			HFIAS quantity	
			HFIAS quality	

Significant levels indicated as *p < .1; **p < .05; ***p < .01. Source: survey data. A high gamma value indicates insensitive results (Rosenbaum, 2005).

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