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Land consolidation, specialization and household diets: Evidence from Rwanda

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Abstract—Despite rapid population growth, increasing land pressure and urbanization, farmers in Sub-Saharan Africa have not intensified their production in a sustainable manner and farming systems remain predominantly subsistence-oriented. In response, developing country governments increasingly implement programs that promote crop intensification and more commercially-oriented agricultural systems. Rwanda’s Crop Intensification Program, launched in 2007, is one such example. However, despite its apparent success in raising production of several priority crops, there are legitimate concerns about the food and nutrition security implications for households that are encouraged to consolidate their land, specialize in their production, and increasingly rely on markets for their food needs. Using recent household survey data and a propensity score matching difference-in-differences method, we find that participation in land consolidation activities had ambiguous consumption effects: it positively impacted on consumption of roots and tubers, but had a negative effect on meat, fish and fruits consumption and the potential availability of vitamin B12 in participants’ diets. This calls for a review of CIP implementation practices to enhance the program’s food and nutrition security outcomes, with improvements in market functioning and market access being potential starting points.

Keywords: Crop intensification; food security; nutrition, impact evaluation; Rwanda

1 INTRODUCTION

Agricultural transformation is broadly understood as the process whereby rising agricultural productivity per worker leads to an increase in the marketable surplus of agricultural commodities and a gradual integration of agricultural and non-agricultural product and factor markets (Timmer 1988). The initial stage of transformation typically entails shifting from diversified and subsistence-oriented production systems towards more specialized and market-oriented ones. Terms such as specialization, (sustainable) intensification and commercialization are often used interchangeably in this context.

Globally, as populations grow and become more urbanized, raising the agricultural production surplus becomes imperative. In short, this requires adoption of sustainable intensification practices in the face of growing land constraints and an increased market orientation for farmers. However, two alarming trends appear to be emerging in Sub-Saharan Africa (SSA). First, while rapid (rural) population growth is associated with declining farm sizes and reduced fallow, especially in land constrained countries (Jayne et al. 2014), sustainable agricultural intensification practices have not been adopted at the pace required to maintain soil fertility (Binswanger-Mkhize and Savastano 2017). Instead, low-productivity, subsistence-oriented smallholder farming systems continue to dominate. Second, even though rapid urbanization and economic growth provide new market opportunities for the rural farm sector, urban food needs are increasingly met through imports (FAO 2012). This should be regarded not only as a missed opportunity for Africa’s rural farm sector to modernize and expand, but importing food is also a drain on scarce foreign exchange reserves.

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These trends provide a rationale for policies that promote specialization, intensification, and commercialization of smallholder agricultural systems. Proponents of commercialization strategies argue that income from crop sales permit farmers to buy better farm inputs. Higher incomes and improved market access also mean farmers can buy diverse and nutritious foods, such that their food and nutrition security would not be at risk even as their production becomes more specialized and commercially-oriented. However, as posited by Fafchamps (1992), the willingness of farmers to produce a surplus is strongly predicated on market access and stability: when markets are weak and uncertain risk averse farmers will favor subsistence farming. Much of the evidence suggests that farmers' production and consumption in SSA remain inseparable, i.e., production continues to determine dietary patterns and farmers are more likely to grow food crops for own consumption when market access is uncertain (Carletto et al. 2015; Radchenko and Corral 2018; Ecker 2018; Sibhatu and Qaim 2018a, 2018b). The concern then is that policies that encourage commercialization may ultimately have detrimental effects on farmers' food and nutrition security if implemented in contexts where markets are underdeveloped.

Against this background, we examine the agricultural commercialization debate and its implications for food and nutrition security further. The context is Rwanda where its government is pursuing a strategy of actively encouraging the transformation of the agricultural sector from a subsistence into a modern, market-oriented sector. While the policy intervention is primarily designed to support agricultural production, the ultimate objective is improved food and nutrition security for all Rwandans. At national level this may be achieved by shifts in food supply, which affects relative food prices and hence households' disposable income levels and consumption patterns. However, our interest in this study is examining how the policy affects beneficiary farm households' consumption directly by affecting what and how much they produce food for own consumption. The policy may also affect farm households' income earned from crop sales, thus influencing their ability to purchase food from markets.

As a small landlocked country with a population of 12 million people, Rwanda faces significant land pressure. Average land holdings are declining (Jayne et al. 2014) and smallholders find it increasingly difficult to feed their families without off-farm income (REMA 2015). Rwanda also imports significant quantities of food, including rice, a commodity in which it has a comparative advantage (Ghins et al. 2017). Policymakers are blaming the traditional subsistence farming system rather than small land holdings for low productivity and the country's failure to be food self-sufficient (Diao et al. 2010). Therefore, the vision for agricultural transformation is not necessarily to increase the size of plots, but to encourage commercial behavior by smallholders and promote better coordination of farmers' activities at village-level. More specifically, Rwanda's Strategic Plan for the Transformation of Agriculture (*Plan Stratégique pour la Transformation de l'Agriculture*) (PSTA) prioritizes sustainable agricultural intensification through crop specialization, increased fertilizer use, and land use consolidation among farmers to raise productivity, promote more efficient service delivery to farmers, and better coordination of farmers' activities. The large-scale Crop Intensification Program (CIP) is the main policy vehicle for achieving these goals. In addition to increased productivity and profitability, CIP also aims to reduce poverty and improve food and nutrition security outcomes (Muhinda and Dusengemungu 2013; MINAGRI 2018).

Despite its scale and prominence, analysis on the effect of CIP on food and nutrition security is scant. Descriptive statistics from a small survey suggest that severely food insecure households consolidate a much larger share of their land under CIP than those that are less food insecure (Cioffo 2014). Isaacs et al. (2016) compare monocropping systems (such as those promoted under CIP) with intercropping practices and find that the latter outperform the former on several counts, including productivity and contribution to diet quality. They conclude that agricultural practices promoted under CIP may not be conducive to improvements in food and nutrition security outcomes. More recently, Weatherspoon et al. (2017) demonstrate how sensitivity to prices and inefficient markets

prevent Rwandan rural households from diversifying their diets, which is suggestive that agricultural intensification may not necessarily improve food and nutrition security outcomes. Despite providing some relevant insights, none of these studies provides robust quantitative results on the direct causal links between participation in land consolidation activities and household consumption behavior.

In addressing this shortcoming in the CIP impact evaluation literature, our study uses recent household panel data and a propensity score matching difference-in-differences (PSM-DiD) method to evaluate the impact of land consolidation carried out through Rwanda's CIP on food consumption patterns and nutrient availability of participants. The results will reveal whether CIP contributes to food and nutrition security objectives as intended. Drawing on literature and evidence elsewhere, we also identify possible policy reforms that could strengthen outcomes of the program. Our results have implications for SSA countries more broadly, where policies designed to fast-track agricultural commercialization continue to emphasize the production side but tend to fall short on addressing market rigidities or adopting mitigation measures for potential adverse nutritional outcomes of such policies.

2 LAND CONSOLIDATION, AGRICULTURAL PERFORMANCE AND NUTRITION OUTCOMES IN RWANDA

Rwanda's CIP was launched in September 2007. Whereas the immediate objective of the program is increased crop productivity and profitability of farming, its long-term goal is to reduce poverty and hunger and contribute to rural development by strengthening markets and developing small businesses (e.g., in processing, trading, and transportation). The idea behind the CIP is to provide inputs and services to groups of farmers who cultivate the same crops in a synchronized manner. CIP targets six priority crops, namely: maize, beans, cassava, rice, wheat, and Irish potato (MINAGRI 2011). The program comprises four components: (i) consolidation of land use; (ii) distribution of improved inputs; (iii) coordinated provision of extension services; and (iv) support to post-harvest handling and storage.

The Rwanda Agricultural Board (RAB), an agency of the Ministry of Agriculture and Animal Resources (MINAGRI), is responsible for CIP implementation. Through consultations with agronomists, RAB identifies CIP target areas and priority crops—grown on a two-crop rotation basis—as well as land consolidation targets across the country's agroecological zones. Land consolidation is implemented at *umudugudu* (village) level, and typically involves groups of 20–25 farmers. Participating farmers would effectively operate as a collective through planting the same crops, coordinating the timing of planting and harvesting, and collectively marketing their crops. Farmers retain their individual property rights and participation is voluntary, but since the program ostensibly provides additional benefits to participants, such as fertilizers, seeds and training, participation may have been implicitly encouraged (MINAGRI 2011, 2018; Cioffo 2014).

Land consolidation under the CIP started in 2008 when about 28,000ha (or 5% of total harvested land in the country) were incorporated into the program. The consolidated land area expanded rapidly in the following years, reaching 600,000ha by 2016 (40% of total harvested land) (RAB 2017). Although the program initially targeted mostly maize, beans became more prominent from 2011 onwards and represented 55% of consolidated land by 2016. During this period, there has been also a significant increase in input usage thanks to the launch of the fertilizer subsidy program in 2007 under the auspices of CIP (IFDC 2017). Although eligible beneficiaries of the subsidy program were supposedly those who met land consolidation criteria, capacity constraints and challenges with the voucher system meant poor targeting with massive under-coverage and leakage. In 2009, for example, only one-quarter of subsidized fertilizer was provided to CIP participants, while the rest was sold on the open market through agro-dealers at subsidized prices (IFDC 2014, 2017). By 2014 the voucher system was abolished, and the subsidy was universally applied.

Information on access to and targeting of extension within the context of CIP is scant. In general, farmers in Rwanda can access extension services in various ways, and it is difficult to differentiate the source or ascertain the quality, appropriateness, or purpose of that advice simply because such information is not captured in the surveys we use. Nevertheless, fieldwork by Uwimana et al. (2015) shows that CIP participants indeed accessed extension services through the program, but non-participants also frequently joined training sessions. As with fertilizer access, it appears there is little or no evidence of preferential targeting of extension services to CIP participants.

In summary, although CIP formally includes components involving land consolidation, access to subsidized inputs, and supply of extension services, there is no suggestion that farmers who consolidated their land were guaranteed—or that those who did not consolidate were denied—access to or received different treatment as far as the input or extension components of the program are concerned. It is therefore appropriate in our analysis to regard land consolidation as the “main pillar” of the CIP—a sentiment echoed by Muhinda and Dusengemungu (2013)—and the principle channel through which CIP participants are differentiated from non-participants.

Figure 1 depicts the broader production shifts, measured in terms of crop-specific outputs (physical quantities) as a share of total output, by CIP and non-CIP crops. While more detailed crop production statistics are omitted due to space constraints, we find that production of maize, cassava and Irish potatoes increased steadily over the period, mostly because of yield growth, while much of the output growth in beans was a result of land expansion. By sharp contrast, paddy rice production stagnated. Although wheat yields rose over the period, a decline in harvested areas led to a decline in output. In general, though, rapid output growth, brought about mostly by yield increases, means CIP crops now account for almost 70% of total crop output, compared to less than 50% in 2005.

Figure 1. Crop production shares in Rwanda, 2005-14

Source: FAOSTAT (2018). Note: Output share is the metric tons (mt) produced as a share of total production. CIP priority crops include maize, beans, cassava, rice, wheat, and Irish potato.

Although poor nutrition remains a concern in Rwanda, progress has been made since the early 2000s. The share of the population that is undernourished measured in terms of the calories available to them declined by 13.8 percentage points between 2000 and 2015, although at around 40%, undernourishment rates remain high. Furthermore, the undernourishment rate increased between 2012 and 2015 from 34% to 40%. The series of Comprehensive Food Security and Vulnerability Analyses (CFSVAs) by the World Food Program (WFP) in Rwanda confirm that food security

generally improved over the course of the last decade, although a slight deterioration is observed for more recent years (Table 1).

Table 1. Food security status of Rwandan households, national estimates, 2006–15

Year	Data collection period	Food secure (%)	Moderately food insecure (%)	Severely food insecure (%)
2006	March-April 2006	65.4	27.9	6.7
2009	February-March 2009	78.5	17.3	4.2
2012	March-April 2012	79.0	17.0	4.0
2015	April-May 2015	74.0	19.0	7.0

Source: WFP (2016). Note: The methodology used to classify households across food security profiles varies between the CFSVAs. The authors reconstructed an indicative mapping.

Other sources reveal that in 2013 more than 50% of calories available in Rwanda came from micronutrient-poor food groups such as cereals, starchy roots and tubers (FAOSTAT 2018). According to the 2015 CFSVA (WFP 2016), while consumption of vitamin A-rich foods is not a concern, protein-rich food items are consumed daily by only 65 percent of households. Moreover, a very small proportion of households regularly consume iron rich food items, making iron deficiency a public concern in Rwanda. About one-fifth of women aged 15-49 years and two-fifths of children aged 6-59 months suffer from anemia as a result (DHS 2015).

3 IDENTIFICATION AND ESTIMATION STRATEGY

The objective of our study is to investigate the causal effect between engaging in land consolidation through CIP participation and household dietary outcomes. The latter is measured in terms of consumption quantities of various food items, the availability of key macro- and micronutrients in the diet, and a Dietary Diversity Score (DDS).

CIP participation is likely driven by several household characteristics, agricultural practices and community features. These may, in turn, also be correlated with our outcome indicators. We deal with this potential selection bias by comparing participants and non-participants who are similar per a set of observable covariates (see Mendola 2007; Kassie et al. 2011; Amare et al. 2012; Magrini and Vigani 2016; Del Prete et al. 2017). The main challenge in observational studies is constructing a credible counterfactual group to capture what would have happened to participating units had they not participated. Since the counterfactual of each individual household can neither be observed nor estimated, impact evaluation techniques focus on the so-called Average Treatment Effect on the Treated (ATT) instead of the effect on individual units.

Formally, we define D as a binary variable equal to one if the farmer participates in the land consolidation activities under CIP and zero otherwise, while Y^1 and Y^0 represent the outcomes of the treated and non-treated units, respectively. The treatment criterion is justified considering that land consolidation is the main pillar of CIP, as argued earlier. The standard approach is to use propensity score matching (PSM), with the ATT expressed as:

$$\tau_{ATT} = E(Y^1 - Y^0 | D = 1) = E[Y^1 | D = 1] - E[Y^0 | D = 1] \quad (1)$$

τ_{ATT} measures the difference between the expected consumption and/or nutritional outcomes with or without land consolidation for those who have access to the program. We can observe the outcome for participants ($E[Y^1 | D = 1]$), but not for those participating had they not been treated ($E[Y^0 | D = 1]$); thus, the assumption required to identify the effect of the treatment is that there is a set of observable characteristics, such that, after controlling for these covariates, the potential outcomes are

independent of the treatment status. This is referred to as the Conditional Independence Assumption (CIA).

The PSM method then identifies a control group—i.e., non-participants that are like participants—using information on observable characteristics (X). The procedure involves two steps: first, estimating the probability of participation in the program (or the propensity score); and, second, comparing non-adopters and adopters with similar probabilities of participating in the program. The PSM estimator can be written as:

$$\tau_{PSM}(X) = E[Y^1|D = 1, P(X)] - E[Y^0|D = 1, P(X)] \quad (2)$$

where $P(X)$ is the propensity score, and the outcomes of the treated households are compared to the outcomes of the nearest non-treated households.

Given that the selection into CIP likely also depends on unobservable characteristics, the CIA may be too strong. For example, if farmers' ability or motivation for participation, neither of which are observed, are key determinants of the participation into the program, it is not possible to fully control for self-selection using PSM. More generally, the approach cannot control for time-invariant and time-variant unobserved heterogeneity. If, however, pre-treatment data are available, and if unobservable factors driving the selection are time-invariant, the CIA assumption can be relaxed. In this case, the effect of the unobservable characteristics can be cancelled out by taking the difference in outcomes before and after the treatment. The difference-in-differences (DiD) approach relies on a less strict assumption, namely that in the absence of treatment the unobserved differences between treatment and control groups are the same over time.

Counterfactual levels for treated and non-treated units can therefore be different, but their time variation is similar, i.e.:

$$E(Y_1^0 - Y_0^0|D = 1) = E(Y_1^0 - Y_0^0|D = 0) \quad (3)$$

where the subscripts denote time periods before (0) and after (1) consolidation. In equation (3) the right-hand term represents the control group; thus, in the absence of treatment, the change in the outcome of treated units is the same as the change in the outcome of non-treated units. While PSM only controls for the bias associated with observable characteristics, DiD controls for the bias associated with observable and unobservable time-invariant characteristics.

Still, one limitation remains, namely that when there is a high degree of heterogeneity between treated and non-treated units, it is difficult to assume that without CIP the outcome variable of these households would have the same trend (Imbens and Wooldridge 2009). More precisely, farmers that are less similar at the beginning of the period are likely to follow different paths over time. By combining the two methodologies (PSM–DiD) we can overcome both limitations. Smith and Todd (2005) find that estimators based on the combined method are more robust than traditional cross-section matching estimators. The steps are: (i) apply a PSM to find non-treated observations that were like the treated observations before the program was implemented; (ii) apply the DiD method to estimate a counterfactual for the change in outcomes in each subgroup of matched units; and (iii) average those double-differences across matched subgroups (Caliendo and Kopeinig 2008). The PSM–DiD estimator is then based on the following identifying assumption:

$$E(Y_1^0 - Y_0^0|D = 1, P(X)) = E(Y_1^0 - Y_0^0|D = 0, P(X)) \quad (4)$$

An important underlying condition required by equation (4) is the existence of a “common support” for the propensity score between participants and non-participants in both periods (Smith and Todd 2005). We restrict our sample to the overlapping region of the estimated propensity scores between control and treated observations to respect this support condition. The PSM–DiD matching estimator we use in our analysis is then given by:

$$\hat{\tau}_{PSM-DID} = \frac{1}{n_1} \sum_{i \in I_1 \cap S_p} \left\{ (Y_{i1}^1 - Y_{i0}^0) - \sum_{i \in I_0 \cap S_p} W(i, j) (Y_{i1}^0 - Y_{i0}^0) \right\} \quad (5)$$

where I_1 and I_0 indicate the set of participants and non-participants, respectively, S_p the region of common support, n_1 the number of treated farmers in the space $I_1 \cap S_p$, and $W(i, j)$ a weighting function depending on the matching estimator employed (Smith and Todd 2005). We use kernel weights to ensure that all available information is exploited as each participating unit is matched to the whole sample of non-participating units (see Heckman et al. 1998).

In line with most empirical applications of the DiD identification strategy, we adopt a standard linear regression specification:

$$Y_{it} = \beta_0 + \beta_1 D_i + \beta_2 Post_t + \alpha_\tau D_i * Post_t + \lambda X_{it} + \mu_{it} \quad (6)$$

where Y_{it} is the outcome variable of interest (e.g., food consumption, nutrient availability, or dietary diversity) for household i at time t ; D is the binary treatment (i.e., participation in land consolidation); $Post$ is a binary variable that takes the value 0 or 1 if the household is observed in pre- or post-consolidation, respectively; and X identifies the set of control variables. The coefficient α_τ is the DiD estimator and captures the treatment effect. As explained further below, we run several specifications of equation (6) to test the robustness of our results.

4 DATA

Our analysis is based on the two latest waves of the nationally representative Integrated Household Living Conditions Surveys (*Enquête Intégrale sur les Conditions de Vie des ménages*) conducted in 2010/11 (EICV3) and 2013/14 (EICV4) (NISR 2012; 2015). The surveys have a panel structure as required by the PSM–DiD method. The merged datasets include a panel sub-sample of 1,259 households with detailed information on land consolidation activities, agricultural practices, and household consumption behavior, collected at two points in time. Since households have about five plots on average, and information is collected at plot-level, we collapse the data to create household-level variables of agricultural production activities.

Treatment and control group identification is based on survey responses to questions on whether individual plots of land cultivated by respondents had been incorporated into a land consolidation activity under CIP. In our benchmark estimation, a household is included in the treatment group if at least one of its plots is committed to the land consolidation program. We also run robustness checks which explore possible differences within the treatment group relating to the share of land consolidated. For these tests, we arbitrarily define treatments groups respectively as “low-intensity consolidators” when less than 50% of a household’s total land area is consolidated, or “high-intensity consolidators” when more than 50% of land area is committed to the program. Although the 50% cutoff is arbitrary, sensitivity checks reveal that our results are reasonably robust to alternative cutoffs such as the mean or median consolidation rates for the population of consolidators. We see that the average consolidation rate among CIP participants increased from 43% to 48% during 2010/11–2013/14. In both years, the largest share of CIP participants consolidated around 15% of their land. A slightly greater percentage of participants consolidate almost all their land in 2013/14 compared to 2010/11, which partially explains the increase in the average consolidation rate.

The estimation strategy also requires a decision about which two groups to compare across the two periods. In both periods, we identify CIP participants and non-participants. However, for our treated group we are particularly interested in the so-called “switchers”, i.e., households who were non-participants in 2010/11 but joined the program in 2013/14. There are 247 such observations in our panel (see Table 2). The control group consists of those 736 households that were excluded from the program (or chose not to participate) in both periods. Our analysis therefore excludes “quitters”, i.e.,

households that participated in 2010/11 but not in 2013/14 (195), as well as the “always treated”, i.e., households that participated in both periods (81).

Our approach to group selection has some advantages but also potential disadvantages. The exclusion of “quitters” and “always treated” allows us to obtain a clean setting of mutually exclusive groups over which to estimate the impact of the program (Pace et al. 2017). However, it reduces the sample size from 1259 to 983 households and could potentially introduce sample selection bias into the analysis as some households may self-select into the omitted groups because of unobserved characteristics at baseline.

Table 2. Number of sample observations in treated and control groups

		Period 2: 2013/14		Total
		Non-participants (0)	Participants (1)	
Period 1: 2010/11	Non-participants (0)	736	247	983
		“never treated” (control group)	“switchers” (<i>treated group</i>)	
	Participants (1)	195	81	276
		“quitters” (excluded)	“always treated” (excluded)	
Total		931	328	1,259

Source: Authors’ estimates based on EICV3 and EICV4 data. Note: Under the high-intensity definition of participants there are 109 observations in the treated group, while the control group stays unchanged.

Consumption quantities, macro- and micronutrient availability, and a DDS serve as outcome variables. Consumption quantities are reported for both home-produced and purchased foods in the EICV datasets. For purchased foods, only the total amount spent is reported; hence we impute quantities based on food prices retrieved from own consumption estimates. Consumption quantities are reported at the household level in the survey, but for our purposes these are converted into grams per capita per day, using an adult equivalent household size measure. For analytical and reporting purposes, individual food items are aggregated into commonly used food groups, namely cereals, meat, eggs, fish, dairy, edible oils, fruits, legumes, vegetables, and roots and tubers.

Macro- and micronutrients are derived from food consumption quantities using food conversion tables produced by Lukmanji et al. (2008) for neighboring Tanzania. Consumption quantities are adjusted such that only the edible portions of foods determine nutrient availability. We focus on two common macronutrients, calories and protein, as well as micronutrients such as minerals (iron and zinc) and vitamins (A, B and C) which are often under-consumed in developing countries (Ecker and Qaim 2011; Azzarri et al. 2015).

The DDS is computed as the average number of food groups consumed by the household in the two days prior to each survey visit. For the sake of consistency, the count is done using the same ten food groups formed for our consumption analysis. A higher score is indicative of a higher quality diet and is strongly correlated with anthropometric measures such as wasting and stunting among children; as such, it is a simple yet powerful nutrition indicator which is also sensitive to shocks and seasonality (Headey and Ecker 2013).

Table 3 reports consumption and nutrient-availability measures in daily units (grams or otherwise) per adult equivalent as well as the DDS. Mean estimates are reported for the combined (treated and untreated) sample as well as separately for the two subsamples. We use *t*-tests to compare differences in means over time for the whole sample as well as differences in means between treated and untreated groups within each survey period. For the whole sample, and measured against a 0.05 *p*-value, we note statistically significant increases in mean consumption levels of cereals, meat, eggs,

fish and fruits, and a significant decline in roots and tubers. We further note small but significant declines in vitamins C and A availability, and a large and statistically significant increase in vitamin B12 availability. The DDS also improves significantly over the period, from 4.85 to 5.01.

The treated and untreated units display very similar dietary patterns in the first period prior to the intervention, with the only significant difference observed for fruit consumption. In the second period, however, we note significantly higher levels of consumption of meat and fish and lower consumption of legumes and roots and tubers among the untreated as compared to the treated. Untreated households also have fewer calories, protein, iron and zinc available in their diets, but more vitamin B12. These results suggest mixed outcomes for treated and untreated households over time. However, simple *t*-tests do not control for possible selection bias, hence we turn to our econometric estimates in the next section.

Table 3. Descriptive statistics and t-tests: daily food consumption quantities and nutrient availability per adult equivalent per day, and dietary diversity 2010/11 and 2013/14

	Whole sample (treated and untreated)			Period 1: 2010/11			Period 2: 2013/14		
	Period 1: 2010/11	Period 2: 2013/14	Equality of means over time (<i>p</i> -values)	Untreated	Treated	Equality of means across groups (<i>p</i> -values)	Untreated	Treated	Equality of means across groups (<i>p</i> -values)
<u>Food consumption (g)</u>									
Cereals	3.58	3.95	0.00	3.60	3.52	0.59	3.92	4.07	0.22
Meat	0.69	0.86	0.01	0.68	0.73	0.65	0.94	0.63	0.00
Eggs	0.09	0.12	0.02	0.10	0.05	0.06	0.12	0.12	0.79
Fish	0.26	0.96	0.00	0.24	0.30	0.29	1.03	0.74	0.00
Dairy	1.07	1.19	0.17	1.13	0.87	0.06	1.20	1.15	0.74
Oil	1.90	1.83	0.19	1.90	1.91	0.86	1.86	1.73	0.12
Fruits	3.97	4.17	0.04	3.87	4.26	0.02	4.23	3.99	0.12
Legumes	4.74	4.75	0.83	4.72	4.78	0.50	4.71	4.86	0.02
Vegetables	4.61	4.58	0.63	4.62	4.58	0.70	4.58	4.60	0.83
Roots & Tubers	6.43	6.21	0.00	6.46	6.34	0.08	6.14	6.40	0.00
<u>Nutrient availability</u>									
Energy (kcal)	7.61	7.64	0.14	7.60	7.62	0.63	7.61	7.73	0.00
Protein (g)	4.01	4.05	0.19	4.01	4.02	0.81	4.02	4.12	0.01
Iron (mg)	2.86	2.82	0.14	2.85	2.87	0.71	2.79	2.91	0.00
Zinc (mg)	2.18	2.19	0.50	2.17	2.19	0.73	2.16	2.29	0.00
Vit C (mg)	5.09	5.03	0.04	5.10	5.09	0.94	5.01	5.09	0.08
Vit B12 (mcg)	0.22	0.35	0.00	0.22	0.22	0.96	0.37	0.27	0.00
Vit A (mcg)	5.84	5.72	0.04	5.83	5.86	0.79	5.71	5.74	0.71
Folate	6.65	6.63	0.49	6.65	6.67	0.61	6.61	6.71	0.02
Diet Diversity	4.85	5.01	0.04	4.85	4.86	0.90	5.03	4.97	0.61

Source: Authors' estimates based on EICV3 and EICV4 data. Note: kcal = kilocalories; g = grams; mg = milligrams; mcg = micrograms (= 0.001mg).

5 RESULTS, MECHANISMS, ROBUSTNESS CHECKS AND DISCUSSION

5.1 CIP impact on consumption, nutrient availability and dietary diversity

The first step of our empirical strategy is to estimate the propensity scores. Following Deininger et al. (2012), Jones et al. (2014) and Sibhatu and Qaim (2018a), we identify three sets of characteristics that can, in principle, drive a household decision to participate in the land consolidation program. These are: (i) households characteristics such as size, number of children, food consumption per adult equivalent, and the household head's marital status, gender, and education; (ii) technical characteristics such as livestock ownership, total land, irrigation (as percentage of planted land), and asset ownership; and (iii) structural characteristics, distinguished between spatial time-invariant covariates (i.e. urban/rural and province dummies) and spatial time-variant characteristics. For the latter group, we insert three community characteristics such as: the average time (in minutes) to reach the nearest food market, which is indicative of how access to markets changes over time for residents in a specific district; the average share of CIP priority crops sold with respect to the total marketed production in the district, which serves as a proxy of the influence of the CIP program on the surrounding agricultural system; and the share of households in the district who had access to credit, which captures the time-varying capacity of the community to relax liquidity constraints. The marginal effects of these variables on the decision to participate are omitted due to space constraints but are available on request. Also omitted are kernel density distributions of the treated and control groups before and after the PSM was implemented, which reveal strong similarity between the two distributions after matching and suggest that once we control for these covariates the potential outcomes are independent of the treatment status.

Turning now to the main results of our analysis, Table 4 reports the DiD estimator (i.e. α_τ in equation (6)) under four different econometric specifications, namely the basic DiD, the PSM-DiD, and for both these, with and without the set of controls, X . The final specification, labelled PSM-DiD- X in Table 4, is our preferred specification, for reasons explained in section 3. With respect to consumption (see upper part of Table 4), a key observation is that our estimated effects are not sensitive to the econometric specification, i.e., the estimators are consistent in magnitude, sign and statistical significance across the specifications. However, this is not the case for the nutrient availability effects (lower part of Table 4), where results are more sensitive to the econometric specification, at least in terms of the size and significance of estimators.

Focusing on results from our preferred specification (PSM-DiD- X), we notice positive consumption effects for cereals (which includes CIP priority crops maize, rice and wheat), eggs, dairy products, oil, legumes (which includes CIP priority crop beans), vegetables, and roots and tubers (which includes CIP priority crops cassava and Irish potato). However, among these it is only the increase in roots and tubers (23.4%) that is statistically significant. We also observe statistically significant and negative impacts on consumption of meat (-36.5%), fish (-33.7%) and fruits (-61.6%) among participants. None of these food groups are prioritized under CIP. Overall, the results suggest that CIP participation encourages increased consumption of CIP priority crops (especially roots and tubers) at the expense of nutritionally-important foods such as meat and fish.

With respect to nutrient availability, treatment effects are much lower and, for the most part, statistically insignificant in our preferred specification as compared to the other econometric specifications. The only significant effect is an 11.5% decline in vitamin B12 availability, which we can relate directly to the decline in meat and fish consumption. The effect on the DDS, although negative, indicating a decline in average number of food groups consumed, is not statistically significant.

Table 4. Impact of participation in land consolidation on consumption, nutrient availability and dietary diversity under alternative specifications

Outcome	Alternative specifications							
	DiD		DiD-X		PSM-DiD		PSM-DiD-X	
	Estimator (α_τ)	Std. err.	Estimator (α_τ)	Std. err.	Estimator (α_τ)	Std. err.	Estimator (α_τ)	Std. err.
<u>Food consumption</u>								
Cereals	0.230	0.193	0.060	0.188	0.206	0.209	0.068	0.202
Meat	-0.354 **	0.137	-0.315 **	0.131	-0.406 ***	0.145	-0.365 ***	0.138
Eggs	0.037	0.035	0.021	0.034	0.004	0.037	-0.011	0.037
Fish	-0.360 ***	0.101	-0.310 ***	0.098	-0.414 ***	0.113	-0.337 ***	0.107
Dairy	0.218	0.203	0.242	0.199	0.316	0.215	0.334	0.209
Oil	-0.153	0.124	-0.056	0.121	-0.121	0.133	-0.038	0.129
Fruits	-0.619 ***	0.221	-0.594 ***	0.209	-0.553 **	0.239	-0.616 ***	0.226
Legumes	0.104	0.099	0.058	0.097	0.178	0.109	0.063	0.102
Vegetables	0.051	0.118	0.023	0.118	0.062	0.127	0.053	0.125
Roots & Tubers	0.380 ***	0.112	0.298 ***	0.104	0.333 ***	0.111	0.234 **	0.101
<u>Nutrient availability</u>								
Energy	0.102 *	0.056	0.035	0.052	0.102 *	0.060	0.019	0.055
Protein	0.092	0.056	0.021	0.052	0.093	0.061	0.001	0.054
Iron	0.104 **	0.052	0.035	0.047	0.109 *	0.056	0.022	0.049
Zinc	0.113 **	0.050	0.040	0.046	0.104 *	0.055	0.018	0.049
Vitamin C	0.089	0.072	0.097	0.068	0.123	0.075	0.094	0.068
Vitamin B12	-0.102 ***	0.036	-0.097 ***	0.034	-0.119 ***	0.038	-0.115 ***	0.036
Vitamin A	0.006	0.138	-0.004	0.139	-0.038	0.148	-0.038	0.149
Folate	0.081	0.064	0.026	0.061	0.103	0.069	0.012	0.062
Diet Diversity Score	-0.081	0.170	-0.033	0.155	-0.054	0.179	-0.005	0.163

Source: Authors' estimates based on EICV3 and EICV4 data.

Note: DiD stands for difference-and-difference; DiD-X for difference and difference with controls X ; PSM-DiD for Propensity Score Matching Difference-in-Difference; and PSM-DiD-X for Propensity Score Matching Difference-in-Difference with controls X . α_τ represents the treatment effect as per equation 6. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

5.2 Mechanisms

Aberman et al.'s (2018) description of the conceptual pathways through which agriculture—and by extension agricultural policy interventions—affects nutrition outcomes serves as a theoretical basis for the causal links that exist between Rwanda's CIP and consumption outcomes. Four impact channels are identified. The first is agriculture as a direct source of food to the farm household. Changes in production or post-harvest practices may improve the quality, diversity, seasonal availability, and quantity of food retained by the producing household for own consumption. The second is agriculture as a source of income from the sale of agricultural products, which can be used to purchase food or other nutrition-relevant items such as healthcare. A third—which relates closely to the first two—is agriculture as moderator of household members' time use and gendered decision-making related to household cropping and spending strategies. The final pathway is agriculture and related policies as a moderator of food supply and demand and hence the availability, diversity and relative prices of foods.

We follow the approach proposed by Acharya et al. (2016) to examine the effect of CIP on consumption outcomes via the pathways identified. This involves identifying a set of mediators—i.e., variables that lie between the treatment and outcome variable on the causal path—as the mechanisms through which the treatment causes the outcome. The quantity of interest is the Average Controlled Direct Effect (ACDE), which estimates the effect of the treatment on the outcome when the mediators are arbitrarily fixed. Recent applications of this method can be found in Cockx et al. (2018), Miller et al. (2018) and Bellemare et al. (2017). These sources can also be consulted for a technical description of the estimation process, which is omitted here.

For the first pathway—agriculture as a direct source of food—we use the Margalef specialization index, a commonly used indicator of agricultural biodiversity (Benin et al. 2004; Sibhatu et al. 2015) and changes in fertilizer prices as proxy mediators. For the second—agriculture as a source of income—we use the share of own consumption in total consumption and the change in the total consumption expenditure per adult equivalent as mediators. Finally, we examine the food market pathway using changes in district-level prices of CIP crops as mediators. Detailed estimation results are available on request. Of interest are the results summarized by Figure 3, which, focusing on the items for which we significant changes in food consumption and nutrient availability (see Table 4), provides a graphical representation of, respectively: the effect of land consolidation when isolating the role of mediators relative to the baseline specification (solid vertical line); and the ACDE when accounting for (i) changes in agricultural practices (*Spec*), (ii) income and consumption effects (*Inc*), (iii) the changes in prices (*P*), and (iv) all three mechanisms jointly (*Tot*).

The results reveal that none of the mediators (*Spec*, *Inc*, and *P*) sufficiently explain the total (*Tot*) effect of land consolidation on consumption and nutrient availability on their own, since we always reject the null hypothesis $H_0: \beta_1 = 0$ at a 5% significance level. In contrast, when accounting for all mediators jointly (*Tot*) we no longer reject the null hypothesis for meat, fish, fruits, and roots and tubers. This can be graphically deducted from the fact that the 95% bootstrapped confidence interval of the treatment variable for those estimates include the zero (dashed vertical line). This suggests that the three sets of mediators, jointly considered, are indeed the primary mechanisms through which land consolidation affects food consumption.

Figure 2. ACDE of land consolidation in regressions of changes in food consumption and nutrient availability

Notes: The horizontal axes report the ACDEs. Horizontal spikes represent the 95% confidence intervals from 1000 bootstrapped replications. Vertical solid line reports the PSM-DiD-X impact of land consolidation as in Table 4 while dashed line indicates the zero effect. *Spec* stands for changes in agricultural practices, *Inc* for income/consumption, *P* for prices and *Tot* for all mechanisms jointly.

Although the individual pathways do not explain the full effect of land consolidation on consumption, Figure 3 still provides interesting insights into their relative weights (see Acharya et al. 2016) since the estimated coefficients reveal what would have been the policy impact if the mediator did not change after treatment. We can thus assert that relative price changes are the most important mechanism affecting the change in meat consumption and Vitamin B12 availability, while agricultural practices are relatively more important in explaining changes in fruits and roots and tubers consumption.

5.3 Robustness Checks

Several robustness checks are performed, for which a detailed discussion is omitted. First, we run tests to assert that the control group is a valid counterfactual for our analysis and the common trends assumption holds. Secondly, we confirm that we can plausibly assume land consolidation to be the main intervention that distinguishes CIP participants from non-participants, despite the program's complexity. Third, we find that results are robust to alternative matching techniques, such as the "nearest neighbor" and "radius" procedures. And finally, we refute concerns that our sample selection procedure, which drops the "always-treated" and the "quitters" could potentially affect the results and show that results are driven only by the decision to join the program and the subsequent change of status.

6 CONCLUSIONS AND POLICY IMPLICATIONS

In this paper, we evaluate the effect of land consolidation on household consumption patterns, nutrient availability, and dietary diversity in the context of Rwanda's Crop Intensification Program (CIP). Results suggest significant growth in consumption of roots and tubers among participants relative to non-participants. In contrast, a negative impact on the consumption of meat, fish and fruits is observed, which is ostensibly linked to the significant negative impact of land consolidation on vitamin B12 availability. Despite these consumption shifts, no significant impact on a Dietary Diversity Score (DDS) is observed. Results are robust to several robustness checks.

CIP can potentially influence consumption outcomes of participants relative to non-participants through various channels, including through its impact on: (i) what and how much farmers produce for own consumption; (ii) household income from crop sales, which influences their ability to purchase food from markets; and (iii) relative food price changes, which influence household income, consumption patterns, and in the longer run, production choices. In examining these impact pathways more closely, we find that farming practices are relatively more important in explaining changes in fruits and roots and tubers consumption, while relative price changes are the most important mechanism affecting the change in meat consumption and Vitamin B12 availability.

These impact pathways are, of course, not independent from one another as agricultural-nutrition linkages are generally complex and difficult to disentangle; for example, relative price changes may influence farmers' marketing decisions, their income levels, or their marketed consumption choices. Nevertheless, our results are sobering and suggest that land consolidation in Rwanda has done little to help participating farm households improve and diversify their diets relative to those of non-participants.

Although further analysis is required—this is beyond the scope of this study due to a lack of relevant data in the Integrated Household Living Conditions Surveys (EICVs)—our results may be indicative of structural constraints in Rwandan agricultural commodity markets that prevent farmers from either accessing markets or profiting from an increased market orientation. It also points at the possibility that production and consumption decisions of Rwandan farmers continue to be non-separable, which is also the case in many other African contexts, whether in impoverished Malawi (Radchenko and Corral 2018) or in fast-transforming Ghana (Ecker 2018).

Our results have important implications for policy in countries such as Rwanda where agricultural specialization, intensification and commercialization are at the center of these countries' rural development strategies. Firstly, while such strategies are potentially important for achieving goals of national food security and food import substitution, they may need to be complemented by interventions aimed at improving nutritional outcomes of farm households, such as the promotion of kitchen gardening or animal protein production. Moreover, in addition to promoting good agronomic practices, extension agents could be trained to impart knowledge on nutritional literacy at home. Secondly, investing in market infrastructure is crucial to allow improved market access not only for selling crops but also for acquiring nutritious foods. Governments should furthermore favor gradual transformation of the agricultural sector rather than attempt quick-fixes through mega-programs to allow more time for markets to mature and better facilitate the agricultural transformation process.

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