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Abstract

Agricultural policies in poor rural developing countries have the potential to improve both household nutrition and agricultural income. But can these policy consequences be reconciled? This is not obvious because many policies are deficient. Moreover, in villages, mismatches have been observed between nutrition and profit indicators. However, incomes raised by such policies may generate nutrition improvement. In Niger, a major program directed to agro-pastoralists is the 3N Initiative. Do these policies enhance households' agricultural profit and dietary intakes? And if so, is it because of an income effect, or through alternative channels? Using an agro-pastoral survey conducted in 2016 Niger, we find that livestock extension services that reduce calorie intake while improving diet diversity operate mostly through an increased household's pastoral profit. In contrast, veterinary services and low-cost livestock feed programs improve diet diversity, but do not affect profit and calories. Because livestock extension services foster households specializing in cattle and sheep rearing and sometimes switching to transhumance, they restrict their access to energy-dense cereals. This generate a perverse consequence on caloric intakes, despite rising animal calories. Therefore, nutritional policy-makers should

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better account for agro-pastoralist access to cereal markets and monitor whether policies generate differential incentives, especially through profit, for specific specialization or lifestyle.

1 Introduction

Agricultural policies in poor developing countries are often motivated by improving the nutritional status of rural populations. Agricultural policies may have the presumed effect of increasing agricultural producers' incomes and enhancing dietary intakes[1]. Can these policy consequences be reconciled? This is far from obvious because many policies are deficient. Moreover, a mismatch between income levels and nutrition indicators has often been observed in household surveys and the literature; for example, richer households in the same village can have worse nutritional status.[2]

In 2011, Niger put in place a major long-term agricultural and food policy initiative denoted "Initiative 3N: les Nigériens Nourissent les Nigériens" (Nigeriens Nourishing Nigeriens), targeted to the livestock sector. Within this plan, the PRAPS and PASEL programs support communal services through the " Maison des Paysans", a local service hub for these households (RNCA, 2015). These two programs enhance access to inputs and extend support, beyond land security and livestock markets, embodying a multiple-service package. They aim at (i) increasing fodder availability by creating livestock feed warehouses, livestock feed banks, mills, and municipal supply centers; (ii) increasing water availability by digging wells; (iii) developing vaccinations for animals; (iv) enhancing extension services targeted toward pastoral and agro-pastoral households; and (v) providing fodder, multi-nutrient block, and fodder seeds to vulnerable pastoralist and agro-pastoralist households[3]. Monitoring the livestock sector also matters for the protection of pastoral ecosystems and their capacity to provide valuable services.

Do these PRAPS and PASEL interventions yield better dietary intake and higher profit for agro-pastoralists in Niger? Are the diets of these households improving because increased pastoral profit translates into better nutrition, or because of alternative channels? For example, Ogutu et al. (2020) finds in Kenya that agricultural commercialization improves dietary quality. Improving dietary intake can boost nutrition status, as measured by anthropometric variables (e.g., in Puentes E. et al. (2016)). This paper attempts to answer these questions using data from a 2016 national agro-pastoral survey in Niger.

The effect of income on dietary intake in less developed countries has long been controversial. This is because increased income may not only change the quantities of nutrients consumed, through variations in food quantities, but it may also affect food sources, which yield different nutrient compositions. For example, in Northern China in the 1980s, Ye and Taylor (1995) estimated that the fraction of grains in calorie and protein intakes fell at higher incomes because consumers switched to higher-priced nutrients.

Among diverse authors, Subramanian and Deaton (1996) find that nutrition, notably calorie intake, is constrained by income in rural Maharashtra in India. This makes income a relevant

[1] Carletto et al. (2015)
[2] Salois et al. (2012); Ogundari and Abdulai (2013)
[3] More details are discussed in Appendix A0.

channel for economic policies in terms of the impact of these policies on nutrition. There are many other cases where income channels matter and may improve nutrition outcomes, notably in Africa. For example, in a community in Western Kenya in 2015, Ogutu et al. (2020) found that commercialization improves the quality and security of the diet in terms of calories, zinc, and iron.

The linkages between agricultural and pastoral activities, diets, and nutrition statuses may be complex. For semi-subsistence agricultural households, raising the level of a household's food output should generally increase its food availability and, as a result, its food intake. However, as agricultural households have become increasingly market-oriented over the last decades, they also typically purchase a substantial share of their food on markets to meet their food needs [4]. Moreover, they can purchase higher-quality food with access to markets and obtain extra income from output sales. In developing contexts, diverse authors have found that a household's production strategies may influence its nutritional and health statuses beyond the effect of its varying agricultural profit.[5] Here, we examine a specific link in these potential interactions: how agricultural profit, versus other channels, may impact dietary intake.

Learning that an effect on nutrition prominently operates through the agricultural profit would corroborate nutrition policy mechanisms targeting profit. This is far from obvious in contexts of missing and imperfect markets, where the separation of production and consumption decisions has often been rejected (Benjamin, 1992; Muller, 2014), and household choices may involve more complex and extended transformations. Moreover, such a result would point the attention of policymakers dealing with nutrition programs toward the financial incentives that producers follow in developing and selecting their activities. In particular, activity specialization or sector changes may occur if policies affect profits and returns discordantly for distinct activities. Furthermore, activity switches may be accompanied by fundamental transformations in the lifestyle of households, including in their location and consumption habits and in the constraints they face in gathering the ingredients for their meals. As we will show below, this may imply, in our setting in Niger, that some policies that foster pastoralist incomes may harm the calorie intake of some beneficiary households.

Instead, finding that the nutrition effect of an agricultural policy operates through channels other than agricultural profit, or other production-level measures, would push policymakers to adjust their perspective on how the policy impacts nutrition and to focus on other interventions less directly connected to market and production processes. For example, intervention can take advantage of local community networks and informal exchanges and gifts, while such an approach may also generate diversion of assistance and power games within and between households. These alternative policy channels may deserve more attention from policymakers interested in nutrition outcomes.

However, producers' health and nutrition status may also directly affect their productivity and efficiency, as found by Croppenstedt and Muller (2000) in Ethiopia. Moreover, programs sometimes simultaneously provide food and production-related assistance (as in Brück et al. (2018)). This implies that potential endogeneity issues may arise when estimating an equation determining dietary intake in which agricultural outputs or profits are included as explanatory factors.

To investigate all these issues, we conduct a statistical mediation analysis of agro-pastoral policies. Specifically, we estimate the fraction of the policy effect on diets (diversity and calories) that goes through variation in pastoral profit (the mediator), versus the policy effects that go through alternative channels. We apply this approach to three components of the PRAPS and PASEL : (i)

[4] Herforth and Harris (2014)

[5] Muller (2009); Dillon et al. (2015)

livestock extension services, (ii) veterinary services, and (iii) feed subsidies. Owing to the integration and coordination mission of Initiative 3N, the PRAPS and PASEL programs concentrate essentially on operations corresponding to these three components (APESS, 2014). This was confirmed by discussions with local officials. Therefore, there is no risk of confusion with other programs. Furthermore, we highlight specialization and lifestyle switches, related to incentives generated by policies for pastoral activities. Finally, we point out an overlooked perverse effect of some policies: household nutrition may be damaged by diet changes accompanying triggered switches in activities and lifestyles. For example, sedentary agricultural households who move to pastoral transhumance lose access to valuable sources of calories. All these questions are relevant for many other agricultural regions, poor developing countries, and possibly many agricultural policies.

The selected policies and outcomes correspond to diverse effects. We find that some interventions (extension services) enjoy significant (positive and negative) average treatment effects on almost all outcomes. The others (veterinary and feed) do not significantly affect calories. This justifies our focus on extension services that we find operate mostly through their effect on profit.

The rest of the paper is organized as follows. In Section 2, we present the context and the data. Section 3 discusses the empirical strategy, while Section 4 reports the estimation results. Finally, Section 5 concludes the paper.

2 Context and Data

2.1 Context

Forty percent of Niger's GDP is derived from the agricultural sector, with 11 percent from livestock (Ministère de l'Elevage, 2016). Eighty-seven percent of the population is involved in the livestock sector as a primary or secondary activity. On average, 10 percent of rural households' income and up to 43 percent of the income of households in pastoral zones comes from livestock. In a survey conducted in 2011 by the National Institute of Statistics in Niger on living standards and agriculture, Zezza and Issa (2012) found that 77 percent reared livestock in rural areas in 2005. These households kept, on average, 2.8 tropical livestock units (TLUs)[6] per household.

Most of the Nigerien households rearing livestock are poor. de Haan (2016) states that between 2008 and 2013, up to 30 percent of the pastoral and agro-pastoral populations were very poor and 30 percent poor, although the asset value of livestock was omitted.

The combined effects of climate change, drought, floods, and desertification, as well as demographic pressure, have brought the pastoral economy into disarray. In the purely pastoral sector, mean livestock ownership is only 1.9 TLUs per capita, and 0.6 TLU per capita in the agro-pastoral sector. These levels are low when compared to "the minimum required to meet basic needs, avoid livestock inbreeding, and recover from drought", which is between 2.5 and 4 TLU per capita for pastoralist households and half of that for agro-pastoralist households. Below this level, households are confined to poverty even in good times. In contrast, households above this threshold can regenerate herds after droughts and use their animals to maintain social networks.

Niger is one of the most vulnerable countries in the world, with 20 percent of rural households being food insecure in any given year (Ballo and Bauer, 2013). In 2010, 26.8 percent of agro-pastoralist households were affected by food insecurity, with global acute malnutrition (GAM)

[6]Tropical livestock units are livestock numbers converted to a common unit. Conversion factors are: cattle = 0.7, sheep = 0.1, goats = 0.1, pigs = 0.2, chickens = 0.01.Visit Harvest Choice website for more details. The benchmark tropical livestock unit is commonly considered an animal of 250 kg live weight (International Livestock Centre for Africa, 1988)

among children under five years very severe in agro-pastoral and pastoral areas. In the Tilaberi region, GAM was up to 14.8 percent, near the WHO's maximum threshold of 15 percent (United State Agency for International Development, 2011). This calamity was largely due to the 2009/2010 food crisis, characterized by harvest collapse, a very short rainfall period, and consecutive years of prolonged droughts.

Several related articles deal with household activities and nutrition in Niger, particularly regarding the assessed impact of cash transfer programs in Niger. Policy effects are found for diverse outcomes, including diets and livestock activities, suggesting that PRAPS and PASEL may also affect these household choices [7]. These studies point to the interest in Niger in policy channels that affect diet (Premand and Barry, 2022). In particular, diet diversity seems to be responsive to additional cash, which suggests a possible influence channel for monetary pastoral profit.

Hoddinott et al. (2018) again examine cash and food transfer programs, and find that received cash is used to buy agricultural inputs. They also find that receiving in-kind food transfers is associated with higher food security and dietary diversity than receiving cash transfers. The monetary channel of the policies has different effects than the in-kind channel in this case. This raises the question of whether this kind of dichotomy arises when considering other policies, for example by separating the effect of enhanced monetary pastoral profit from the direct effects of policies that may be non-monetary.

In Niger, Asfaw et al. (2018) emphasize crop and labor diversification strategies of rural agricultural households, and find that crop diversification favors poor households' access to decent calorie intakes. Asfaw et al. (2016) find in Niger that extension services play a strong role in the adoption of modern inputs. This is consistent with our emphasis on extension services. In this paper, we show hints that an opposite specialization strategy, i.e., switching to pastoralism may yield a drop in calorie intake. Specialization can be fostered by income incentives associated with some pastoral policies like extension services. Upton (2019) finds a strong positive correlation of livestock holdings with well-being levels, and pastoral specialization, consistently with living standards of pastoralists in Niger that are typically higher than those of rural households who rely only on cultivated crops.

This paper uses data from a specialized survey conducted by the Ministry of Livestock in Niger. This survey was conducted for monitoring two World Bank projects: "PRAPS: Projet Régional d'Appui au Pastoralism au Sahel" and "PASEL: Programme d'Appui au Secteur de l'Elevage". We can access only the first wave of this survey, conducted in October 2016[8]. The survey covered the seven regions of the country in which 1,350 pastoral and agro-pastoral households were sampled. First, 90 villages were selected proportionally to their size without stratification, as recorded from the national directory of localities. Then, 15 households were randomly drawn from each of the villages with stratification with respect to the herd size (small, medium, and large herders) [9].

The surveyed households were asked about their socio-demographic characteristics, budget, food consumption, agro-pastoral production, livestock holdings, agro-pastoral sales, pastoral cost, and the prices they face individually. The same survey provides information on the households' different shocks (shocks related to animal fodder, animal diseases, and water access) and their strategies in response to these shocks. Finally, these households stated not only whether they

[7] Stoeffler et al. (2020), Premand and Stoeffler (2022)

[8] The other waves, which are not accessible officially, cover too small a subsample to be usable for our analyses.

[9] Some agro-pastoral policies could induce non-pastoral households to enter these activities and we cannot control this potential entry with these data. On the other hand, we found no indications that such a process is taking place, neither in the academic nor the administrative literature, nor Niger's statistical sources nor during the interventions and focus groups that we conducted in Niger.

were treated for each of the considered interventions of PRAPS-PASEL: input subsidies, veterinary services, and livestock extension services; but also provided an individual assessment of local easiness of access of each intervention. According to officials of the survey, almost all the surveyed participants in these interventions were already using them when the collection started (Altine, 2024). This timing is also supported by the starting dates of the PRAPS-PASEL operations that were between 2013-2015, thus leaving ample time for households who choose to participate to do it[10].

The livestock extension services in PRAPS-PASEL include two types of professional advice: the first is related to the use of livestock feed, while the second encourages households to use modern animal health services, appropriate breeding techniques, and modern feeding. To obtain the first type of advice, households must visit a livestock feed bank called "the peasant house". Government technical services, municipalities, farmers' associations, or cooperatives hold these peasants' houses. The livestock feed bank aims to i) bring livestock feed closer to remote households and ii) provide a "security stock" that can be mobilized during the hot and dry season when livestock feed is scarce on the market and particularly expensive. The second type of advice is routinely provided yearly at the start of the pastoral season. It is offered by farmers' associations and the technical services department of the Ministry of Livestock.

An individual private veterinarian or a local private veterinary assistant delivers veterinary services. On the one hand, private veterinarians can be found at the department level. They often hold veterinary medicines with the mandate to deliver free vaccination campaigns financed by the government. Local private veterinary services are led by a private veterinarian who runs a network of about thirty auxiliaries. These auxiliaries may be community agents, such as villagers chosen by the community, who are trained and associated with the private veterinarian. Local private veterinarians and their auxiliaries provide households with various animal health services, such as vaccination, treatment of animal diseases, and advice on a wide array of issues.

Every year, the government assesses the country's fodder deficit and purchases fodder to meet the needs of deficit areas. This fodder is offered to peasant households at moderate prices. However, it never covers more than fifty percent of what is needed (Ministère de l'Elevage, 2015). Veterinary services and subsidized feed may both reduce livestock mortality and diseases and thus not only safeguard milk production but also limit transmissible diseases for humans, which may improve the health and nutrition of the latter.

Therefore, it is expected that the main impact of these three interventions should be to enhance the size and the output of the herd. This can result in increased agropastoral profit levels when the animals are sold, or in larger consumption of animal products when they directly are used or killed for household consumption. Broader effects, on health, nutrition, and social relationships may also occur, directly or indirectly in the lines of reasonings above-mentioned with the literature.

Furthermore, to generate instrumental variables addressing the endogeneity of pastoral profit, GPS coordinates are used for matching each surveyed household with local precipitations and temperature data as detailed in Appendix A1. This study focuses on households with sheep and cattle, our reference population, as explained in Appendix A2, that discusses the targeting of the interventions that exclude household with no pastoral activities.

[10]These are the questions posed to the surveyed households to assess their participation in the intervention and evaluate their appreciation of these interventions: (i)Have you used these services this year? (1 if regularly or frequently; 0 if never or very rarely) (ii) What is your assessment of the physical access to these services, on a scale from 1 to 4, where 1 is 'very difficult' and 4 is 'very easy'? (iii) What is your assessment of the cost of these services, on a scale from 1 to 4, where 1 is 'much lower than the market price' and 4 is 'much higher than the market price'? (iv) What is your assessment of the quality and efficacy of these services, on a scale from 1 to 4, where 1 is 'very bad' and 4 is 'excellent'?"

2.2 Summary statistics

Table 1 reports some descriptive statistics for the variables used in this paper. Our sample's average age of the household head is 45 years, and nearly 95 percent are male. Most heads (94 percent) have no education, and only 4 percent received primary education. The average size of a household is 7 members, most of whom are children.

Our sample is mainly composed of households whose head belongs to the Fulani ethnic group (55 percent), followed by Tuareg (23 percent) and Haussa (14 percent). The country's seven regions are grouped into two zones: the North and the South. The North is formed by the Agadez, Diffa, Maradi, and Zinder regions, and the South is formed by the Tahoua, Dosso, and Tillabery regions. Most households in our sample (60 percent) are in the South.

As previously stated, households were classified into three categories according to the size of their herds: small herders (5 sheep and 4 cattle, on average), medium herders (10 sheep and 8 cattle), and large herders (29 sheep and 14 cattle). The majority (56 percent) of households in our sample are herders. Only 15 percent of households surveyed are large herders. For all categories combined, the average number of animals per household is ten for sheep and seven for cattle.

Table 1: Summary statistics

Variables	N. Obs	Mean	Std. Dev	Min	P25	P50	P75	Max
Sociodemographic variables								
Sex of household head (1 if male)	600	0.95	0.23	0	-	-	-	1
Age of household head	596	44.76	14.66	17	33	42	55	92
Education level of household head								
- None (1 if yes and 0 otherwise)	600	0.94	0.23	0	-	-	-	1
- Primary (1 if yes and 0 otherwise)	600	0.04	0.19	0	-	-	-	1
Household size	600	7.14	3.68	1	4	7	9	25
Number of children (0-3 years old)	600	0.82	0.97	0	0	2	1	6
Number of children (4-10 years old)	600	2.02	1.66	0	1	2	3	9
Number of youths (11-16 years old)	600	0.88	1.08	0	0	1	1	8
Number of young adults (17-20 years old)	600	0.80	0.93	0	0	1	1	5
Number of adults (20 years old)	600	2.65	1.52	0	2	2	3	11
Area of residence (1 if in the South)	600	0.60	0.49	0	-	-	-	1
Ethnic group								
- Tuareg (1 if yes and 0 otherwise)	600	0.23	0.42	0	-	-	-	1
- Haussa (1 if yes and 0 otherwise)	600	0.14	0.35	0	-	-	-	1
- Fulani (1 if yes and 0 otherwise)	600	0.55	0.49	0	-	-	-	1
Livestock holding								
Number of sheep	600	10.04	31.44	0	1	4	10	130
Number of cattle	600	6.55	9.36	0	0	3	8	64
Livestock holding category								
Small producer	600	0.56	0.5	0	-	-	-	1
Large producer	600	0.15	0.36	0	-	-	-	1
Outcomes variables								
Calorie intake per capita per day (kcal)	600	3,987	3,874	16.70	1,585	2,775	4,921	21,166
Calorie intake per capita per day from cereals (kcal)	600	3,242	3,222	15.66	1,214	2,192	3,825	20,984
Calorie intake per capita per day from animal food product (kcal)	600	208.81	980	0	5.11	41.08	102	12,539
Household dietary diversity score	600	5.39	1.73	1	4	5.5	7	9
Annual pastoral profit (Millions of CFA)	600	3.89	18.3	-1.63	0	0.21	1.15	257
Policies								
Participation in livestock extension services (1 if yes and 0 otherwise)	600	0.19	0.39	0	-	-	-	1
Participation in veterinary services (1 if yes and 0 otherwise)	600	0.20	0.40	0	-	-	-	1
Participation in low-cost livestock feed (1 if yes and 0 otherwise)	600	0.15	0.35	0	-	-	-	1

Notes: To calculate the calorie intake from cereals and animal food products, the considered cereals are millet, sorghum, bread, maize, and edible pasta, while the animal food products considered are meat, poultry, fish, fresh milk, curdled milk, and cheese.

The household dietary diversity score varies between 1 and 9, with an average of 5. This means that, on average, the surveyed households consume five different food groups during the year. Over this year, food consumption provided an average of 3,987 kcal per person per day for each household. However, 25 percent of surveyed households have a calorie energy intake of less than 1,584 kcal per person per day, while 50 percent have less than 2,775 kcal per day. Measurement issues and outliers are discussed in Appendix A3.

Table 1 shows that the profit level varies greatly across households. On average, the annual pastoral profit is 3.89 million CFA francs, mainly driven by the high pastoral profit level of medium and large herders. Over the survey period, 25 percent of households had a zero pastoral profit, while half made a pastoral profit of more than 214,073 CFA francs. The households with zero pastoral profit correspond to those with very limited pastoral activity. The maximum pastoral profit loss observed is nearly 1.6 million CFA francs. This may partly be due to measurement errors and partly because annual pastoral profit is an imperfect measure of economic activity for livestock rearing, where the production horizon may span several years.

A concern is that most observed high-profit levels may correspond to distress sales by vulnerable households suffering a catastrophic shock. Although this would not change the estimation results, it would alter their interpretation. However, an examination (shown in Appendix A4) of the characteristics of high-profit households in this sample established that these data are far from being explained by distress sales. The profits from other agricultural activities are not observed.

The constructions of the outcome variables – the household dietary diversity score, the household caloric intake per capita, and the household pastoral profit – are presented in Appendix A4. They are each transformed into a logarithmic form for the econometric analysis. When transforming the annual pastoral profit into logs, we add a constant amount to the profit level to accommodate negative values. The transformed profits are log (profit + constant), where the constant equals the minimum observed profit value in absolute terms plus one.

In the sample, 20 percent of the surveyed households have access to private veterinary services, while only 19 percent and 15 percent state that they have access to extension services and low-cost livestock feed (see Appendix A5 for more details).

3 Empirical Strategy

We investigate the mechanisms behind agricultural policies' impact on household dietary intake, specifically the role of pastoral profit. By contrast, mainstream policy evaluation methods primarily focus on the average treatment effect rather than the underlying causal channels that drive this effect.

Analyzing the causal channels through which a policy effect occurs, with a specific interest in the role of a particular mediator variable, is referred to as causal mediation analysis[11]. Heckman and Pinto (2015) has explored mediators in agricultural production using average treatment effect (ATE) estimators. Our approach to mixing ATE estimators and regression estimators is similar to their econometric setting (p. 4, or eq. 19, p. 16). There is growing interest in using causal mediation analysis in economics[12]. We apply it to assess the fraction of the impact of agricultural policies on the dietary intake of pastoralist households in Niger that is mediated by pastoral profit.

[11] Imai et al. (2011)

[12] See Kosec et al. (2018). For example, mediation analysis has been used to analyze the impact of promotion campaigns for the adoption of staple foods on dietary intake (De Brauw et al., 2018). Imai et al. (2011) explore the extension of mediation analysis to general settings that include nonlinear models. Given the limited sample size, we prefer to focus on linear models.

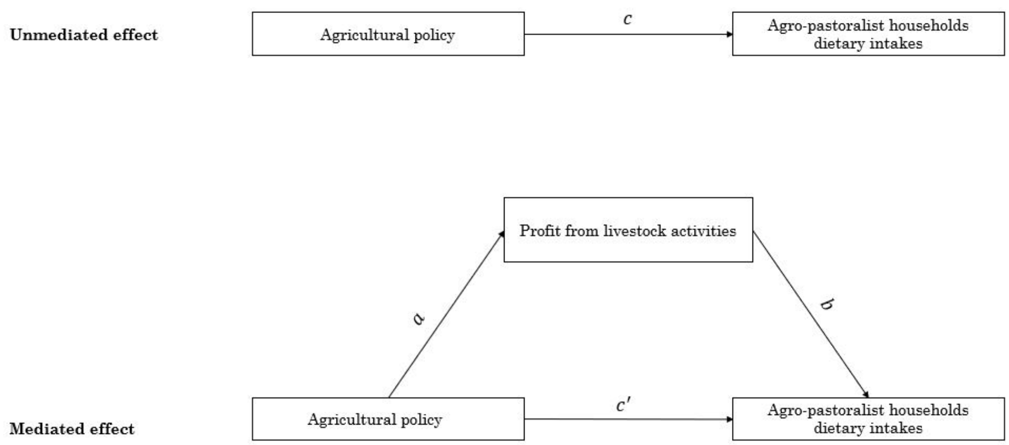

Figure 1: Causal links

This strategy is spelled out in terms of the four links (*a*, *b*, *c*, and *c*′) in Figure 1. The first link represents the total effect (*c* in Figure 1) of the selected agricultural policies on the dietary intakes of agro-pastoralist households. The link *a* represents the effect of the selected policies on pastoral profit, which is the mediator. The link *b* shows the effect of pastoral profit on the households' dietary intake. Links *a* and *b* are used to assess the indirect effect of the policies on the households' dietary intake, that is, the effect channeled by pastoral profit. Finally, the last link *c*′ represents the direct effect of the policies on the households' dietary intake, that is, the effect through channels other than pastoral profit.

3.1 Estimating unmediated effect (link c) of interventions

In this step, we estimate a model of selection on observables based on the potential outcomes, with and without treatment. In Niger, households who can access them may choose to participate or not in the considered interventions. Without randomized control trials and panel data, these interventions in Niger must be evaluated based on observable covariates. In principle, the selection of households into each intervention should arise from three sources: physical and institutional entry barriers, sorting and selection by local administration agents, including in the "Maison des Paysans"; and self-selection by the households themselves, according to their preferences and needs. The first two sources are controlled by a constructed indicator of local access, extrapolated from local opinions about the quality of access, and anchored by regression on a set of exogenous characteristics. Other included control may also correlate with entry obstacles faced by households, such as being in more isolated places, belonging to some ethnic groups that may be favored or discriminated against by local agents, and low education levels that may hamper the reception of information about an intervention, or its predicted implementation, and diverse demographic characteristics of the family that may designate the household as lower priority target to the local agents to include them in the interventions. Finally, the factors correlated with the household preferences and needs largely overlay with most of the above controls, especially for the age-gender classes that should be strongly correlated with the household's nutritional needs, and therefore with its motivation to participate in these interventions. Probit estimates of household participation are shown in Appendix A7.

Given these observed and constructed controls, our identification strategy of policy effects assumes conditional mean independence between the treatment and the outcomes. This assumption is made more plausible by the typical delays in households' use of interventions at the start date of the survey or before, and by the recorded agricultural and dietary outcomes that occurred after this starting date.

Due to the limited data, addressing identification with an approximate selection hypothesis based on observables seems better than neglecting selection and associated endogeneity issues. Moreover, relaxing the assumptions is possible thanks to the double robustness of the used estimation method, as discussed below. Some rationale for considering separately the effects of the different interventions is discussed in Appendix A6. There is no information about some grouping or difference in targeting or allocation between these interventions in the survey documents or in the information about the programs. Since we were unable to find any distinction in the other documents that we consulted and during our discussions with numerous agents in Niger, we assume that such patterns were not planned at the time of the intervention design. Of course, the decisions of the targeted households to participate and various unobserved practical implementation constraints should vary across these interventions.

To construct a counterfactual, we use the inverse probability weighted regression adjustment (IPWRA) method, discussed in Wooldridge (2010), which combines regression adjustment (RA) and inverse probability weighting (IPW). A model is specified for the outcome

$$Y_i = X_i'\beta + \varepsilon_i \tag{1}$$

and another for the treatment, based on the predicted propensity score:

$$\Pr\left(T_i = 1\right) = \Phi\left(X_i'\hat{\lambda}\right), \text{ where } \Phi \text{ is the cdf of the standardized normal law,} \tag{2}$$

for households i = 1…N, in our sample. In equations, (1) and (2), X_i is a set of covariates that influence both the outcome, Y_i, and the dummy variable for treatment, T_i. β and λ are parameter vectors to estimate, while ε_i is an error term. Under the usual ignorability assumption, the IPWRA method delivers a consistent estimator of the effect of the treatment, even if either of the two models is miss-specified ('double robustness property' see Wooldridge (2007)).

The observed characteristics that are assumed to affect the outcomes and households' participation are sex, highest reached education level, and age of the household head, dwelling location (North or South), the proportion of children under 3, the proportion of children between 4 and 10 years old, and the proportions of youth (11-16 years old) and young adults (17-20 years old). These characteristics can affect household food demand and diet composition. For example, households with children may consume more milk, even though babies would rather drink their mother's milk. Furthermore, some characteristics of households, such as the sex of the head of the household, the age, or level of education, can affect their access to a given intervention. Educated households can more easily obtain policy information or be better able to implement the advice provided. Finally, in principle, the design of the considered policies is that all agro-pastoral and pastoral households should be targeted, which amounts to a huge population potentially. In practice, the interventions considered bring direct benefits almost exclusively to the owner of cattle and sheep, which implies limiting the targeted population. For example, subsidized feed is for these animals. Consequently, the PRAPS-PASEL survey has collected complete information for these households only, which confirms this target specification, and excludes households only having poultry, for example. However, due to limited resources, it may be that, at the time of implementation, specific households based on these socio-demographic characteristics may have been favored by local agents. Information about such informal priority rules is not available.

We include household ethnic group, but omit the pre-survey livestock-holding category as covariate in the treatment models. Here, caution is exercised due to possible endogeneity issues, even if this category may drive a household's willingness to access a policy or its likelihood of being selected by public officials. Recall that the livestock holding categories correspond to a period before the survey and policy. However, because it may be potentially endogenous in production processes, we do not include these categories as covariates of the profit outcome. In addition, exogenous intervention access indicators that have been constructed at the cluster level, play a pivotal role in explaining and instrumenting individual participation in the programs. Appendix A7 compares the control and treated groups, for each intervention, in terms of all covariates. The groups are exclusively made up of agro-pastoral and pastoral households, as defined in Appendix A2 by their ownership of cattle and sheep.

For the IPWRA method, the treatment effect is obtained by first estimating the parameters of the treatment model to generate the predicted probability to be treated for each individual, $\Phi(X_i'\hat{\lambda})$, where$\hat{\lambda}$ is the probit estimate of λ. The inverse of the predicted probabilities are used as weights in the regressions of the outcome models for each treatment (0 and 1) to obtain each individual predicted outcome specific to each treatment level. The two treatment groups must satisfy a common support assumption for this comparison to be meaningful and produce consistent estimates. This is indeed the case, as shown in Appendix A8.

To estimate the parameters of a linear regression model for the outcome, the IPW linear least-squares regression is used for each separate treatment:

$$\min_{\beta_0} \sum_i^N \frac{\left[Y_i - X_i'\beta_0\right]^2}{1 - \Phi(X_i'\hat{\lambda})} \quad if \;\; T_i = 0, \tag{3}$$

and

$$\min_{\beta_1} \sum_i^N \frac{\left[Y_i - X_i'\beta_1\right]^2}{\Phi(X_i'\hat{\lambda})} \quad if \;\; T_i = 1 \tag{4}$$

Finally, the average treatment effect (ATE) is estimated by computing the difference between the means of the predicted outcomes of the two treatment groups:

$$A\hat{T}E = \frac{1}{N}\sum_i^N [X_i'(\hat{\beta}_1 - \hat{\beta}_0)], \tag{5}$$

where $\hat{\beta}_1$ and $\hat{\beta}_0$ are, respectively, the IPWRA estimated parameters of the outcome model for $T_i = 1$ and $T_i = 0$. This approach can also be used to estimate the impact of the selected agricultural policies on the presumed mediator, that is, annual pastoral profit, by substituting it as the outcome variable.

Threats to identification in estimating the propensity scores and regressions arise from the limited observations. Identifying the impact of agricultural policies on profit and the impact of profit on calories is hard, and we must rely on hypotheses that may only hold approximately, particularly for the propensity scores. However, this is the only way to take advantage of the available cross-sectional information and examine these policies in Niger and their potential channels. Fortunately, the double-robustness property of the IPWRA somewhat protects the inference against biases in either the propensity score model or the regression model, and we take advantage of this. Alternatively, the results can always be read as merely information or correlations, rather than causality, if the identification assumptions are found too unpalatable.

One issue is that there is limited baseline information on households before policy, especially to estimate propensity scores. Consequently, the correction weights used in the regressions are instead based on 'stable' covariates. One of these covariates is the region of residence, which is underscored by the observed internal migration patterns in Niger (INS, 2012). Although some migrations occur between regions, most people remain in their regions of birth (INS, 2012). For instance, regions like Diffa, Maradi, Tahoua, and Zinder have retention rates of 97 percent, 98 percent, 98 percent, and 98 percent, respectively, suggesting that most of their natives have stayed. On the other hand, regions like Niamey and Agadez have inbound migrations indices of 30 percent and 15 percent. However, most other regions, such as Diffa, Dosso, Maradi, Tahoua, Tillabéry, and Zinder, have low inbound migrations between 1 percent to 3 percent.

The composition of the household can be unstable due to migration of young members due to children being fostered by relatives in other households. Birth, death, and other migrations can also be an issue. However, while these phenomena exist, they do not perturb the general picture of household composition in this sample over the limited span studied.

3.2 Effect of pastoral profit

Let us now discuss the estimation method of the impact of the mediator on the dietary intake of the household (link b in Figure 1). We use a regression to estimate this mean effect, with control variables (X_i in the model below) that are the same as in the above outcomes equations, and where livestock-holding categories are excluded to avoid endogeneity issues.

However, as mentioned above, feedback may occur between households' production strategies and nutritional status, and unobserved confounders may perturb the observed relationship of these variables. To control for this, we run a weighted 2SLS regression to estimate the effect of pastoral profit on dietary intake. The weights are the same as those used in the IPWRA model; that is, they are obtained by estimating the parameters of the treatment model to generate the predicted probabilities to be treated for each household, and the inverse of these predicted probabilities is used as weights. This approach can be denoted as IPW-2SLS. By doing so, we aim not only to control the endogeneity of pastoral profit but also to control the selection bias of the treatment variable dummy included in the equation. The instrument for profit is the mean local incidence of livestock disease faced by households in each cluster (that is, the proportion of households who suffered from livestock disease at the locality level). To address potential bias and endogeneity in self-reports, which could correlate with profit, we calculated the mean incidence of livestock disease at the cluster level excluding the specific household.

Formally, this amounts to jointly estimating the following two equations for each policy j using a weighted 2SLS approach:

$$\begin{aligned} Log(Profit)_i &= \alpha_0 + T_{ij}\alpha_1 + Z_i'\alpha_2 + X_i'\alpha_3 + u_i, \\ \text{and} \quad Y_i &= \gamma_0 + Log(Profit)_i\gamma_1 + T_{ij}\gamma_2 + X'_i\gamma_3 + v_i \end{aligned} \tag{6}$$

The weights used in these equations are defined as follows:

$$w_i = \begin{cases} \frac{1}{\hat{P}_i}, & \text{if } T_{ij} = 1 \text{ (treated household)}, \\ \frac{1}{1-\hat{P}_i}, & \text{if } T_{ij} = 0 \text{ (non-treated household)}. \end{cases}$$

Here, $\hat{P}_i$ is the predicted probability of treatment for the i^{th} household, estimated with equation 2

The γ's and the α's are vectors of parameters to be estimated, while u_i and v_i are error terms. T_{ij} is the j^{th} policy's treatment dummy for the i^{th} household, Y_i is here the outcome of interest, X_i are control variables, while Z_i denotes the instrument for this household. Although not indicated to avoid notation clutter, the parameters and error terms vary depending on the policy considered.

The system (6) allows us to estimate the impact of the mediator on the dietary intake of households while controlling the participation of households in a policy. The joint presence of the profit and policy variables in the outcome equation corresponds to the indirect and direct effects, respectively. The other controls are the same as those used for the ATE estimates of the policies.

The main instrument is assumed to be uncorrelated with the error terms in the equations of the calorie intake and the dietary diversity score. Given this exclusion restriction, the instrument impacts the outcomes solely through its associations with the logarithm of pastoral profit. The exclusion restriction for the mean local incidence of livestock disease is justified not only by the fact that it is typically unexpected by households, but also because we use the mean response of all households in the cluster, of which the own observation has been excluded, as the instrument. This instrument serves as a good proxy for pastoral productivity. Livestock diseases significantly affect the health and productivity of animals, directly influencing the profit margins of pastoralists. High incidence rates of livestock diseases can lead to increased mortality, reduced fertility, and lower milk and meat yields, thereby diminishing pastoral profits. This measure captures the localized impact of animal health on pastoral activities and provides a clear link to profitability without being directly confounded by household dietary intake patterns.

Although exclusion restrictions are ultimately untestable, the observed correlations in the data are encouraging (not shown while available). The absolute value of the correlation coefficients of the instrument with each outcome is approximately twice smaller than the corresponding value for the same instrument with log profit. This is consistent with the instrument mostly affecting the outcome through its correlation with pastoral profit [13].

In the IPW-2SLS estimation of System 6, γ_1 captures the effect in the variation of pastoral profit (due to livestock disease) on the dietary outcome Y_i, while γ_2 captures the effect of the policy. This is based on the assumption that livestock disease affects Y_i only through pastoral profit. The presence of the treatment dummy in the second equation of System 6 aligns with the investigation of mediation effects, by estimating how the treatment affects the outcome while controlling for the profit variable in the same equation. Consistently with the 2SLS formula, the treatment dummy must also be included in the first-stage equation. That is, in this context, the treatment variable is considered to be akin to an exogenous regressor due to the use of weights that adjust for selection bias. The controls introduced to justify ignorability in the estimation of the average effect of treatment are also introduced in the two stages of the IPW-2SLS. This approach

[13] Local weather indicators, such as rains and temperature, would come to mind as possible instruments. We refrain from using them for two reasons. First, climatic shocks may affect food habits. For example, high temperatures encourage drinking beverages, such as milk. Second, using too many instruments actually degrades the finite sample statistical property of the estimates, and it is cautious to avoid this.

strengthen the validity of the estimated effects by addressing both endogeneity and selection bias in a unified framework.

We take advantage of the pre-test estimates approach by using the more efficient OLS estimates when the null hypothesis of pastoral profit exogeneity, cannot be rejected by the result of the Hausman test.

3.3 Estimating the indirect and direct effects

As mentioned before, the indirect effect is the effect that is channeled through the pastoral profit, while the direct effect (link c' in Figure 1) is the effect that passes through channels other than pastoral profit. These two effects form the total effect (link c in Figure 1).

The indirect effect is calculated as the product of the effect of policies on the mediator and the effect of the mediator on household dietary intake (links a and b, respectively, in Figure 1). The first effect, a, is estimated, on average, from the ATE formula in Equation (5), while the second effect, b, is obtained from the estimates of parameter γ_1 in System (6). The direct effect, c', is therefore measured by parameter γ_2 as the effect of the policies on the outcome when the effect of the mediator is controlled for. The total effect and its decomposition into direct and indirect effects, along with their corresponding standard errors, are computed using jackknife estimation. This approach accounts for multiple estimation stages and a limited sample size.

4 Results

We now present the estimation results in four subsections corresponding to the links in Figure 1. We focus on extension services since the other policies are found to have insignificant effects on calories and are less interesting. In contrast, extension services are found to imply a significant drop in calorie intake, and we examine why. We find that extension services operate predominantly through pastoral profit. These results point out perverse income incentives that foster the substitution of animal products for energy-intensive cereals. This substitution may arise from households switching to a transhumance lifestyle, or to high own-produce consumption rates with switches in production, or other changes in tastes or social influences.

4.1 Total effects of policies on dietary intake

The estimates of the unmediated, or total, effect of each of the three interventions on dietary intake are reported in Table 2. The hypothesis that the distribution of covariates is the same for the control and treatment groups is not rejected for any of the three interventions. These distributions and test results are presented in Section A7 of the Appendix, along with the distribution graphs of the propensity scores for each intervention for the control and treatment groups (see Section A8 of the Appendix). The graphs indicate that, in all cases, the common support condition, which allows the estimation of the conditional means of the outcome for each of the treated and control groups, is satisfied with these data. Specifically, the estimated probabilities of households being observed exclusively in one of these groups, given certain covariate values, are negligible. The similarity in the distributions of covariates for the treated and control groups provides confidence that the two groups are comparable for the covariates used in the estimations after IPWRA weighting. Finally, the covariate balance is not rejected at the 5 percent significance level.

The average treatment effect of each of the three interventions is significantly positive for the dietary diversity score. Households that participated in extension services experienced a 12.3 percent increase in their dietary diversity score compared to those that did not. Participation in veterinary services also increased the dietary diversity score by 18.4 percent. Finally, the total average effect of low-cost livestock feed deliveries increased dietary diversity by 23 percent.

Regarding daily per capita calorie intake, only extension services have a significant impact. They decrease daily per capita calorie intake by 37.5 percent for households that participated in them, which is considerable and warrants further examination of these services. The other two interventions do not have significant effects on total calorie intake. The effects of each intervention are similar when considering calorie intake solely from cereals. This suggests that a decline in cereal consumption could explain the unexpected negative impact of extension services on total calorie intake.

However, opposite intervention effects are observed for calorie intake from animal food products. The results of the three interventions—extension services, veterinary services, and low-cost feed programs—show positive and significant effects. These positive effects are consistent with the presumed beneficial contributions of the interventions to the dietary diversity score. Increasing dietary diversity for households with diets primarily composed of cereals generally implies increasing their consumption of animal food products. However, the negative impact of extension services on total calorie intake and caloric intake from cereals raises questions about their origin. Our causal mediation analysis sheds some light on this.

Table 2: ATEs of interventions on households' dietary intake

	Log of household dietary diversity score	Log of total daily per capita calorie intake	Log of daily per capita calorie intake from cereals	Log of daily per capita calorie intake from animals
	ATE	ATE	ATE	ATE
Participation in extension services	0.123*** (0.000)	-0.375** (0.021)	-0.439** (0.010)	0.491** (0.022)
Testing covariates balance: (Chi-square test)	(0.347)	(0.347)	(0.347)	(0.347)
Number of Observations	595	595	595	595
Participation in veterinary services	0.184*** (0.000)	-0.199 (0.100)	-0.272** (0.026)	0.420** (0.045)
Testing covariates balance (Chi-square test)	(0.712)	(0.712)	(0.712)	(0.712)
Number of Observations	595	595	595	595
Participation in low-cost livestock feed	0.230*** (0.000)	0.076 (0.555)	0.078 (0.565)	0.868*** (0.000)
Testing covariates balance (Chi-square test)	(0.767)	(0.767)	(0.767)	(0.767)
Number of Observations	585	585	585	585

Notes: This table provides an overview of the average treatment effects (ATEs) of the investigated interventions, with each intervention displayed in rows and the respective outcomes in columns. The ATE is presented separately for each intervention and outcome within the cells, with p-values indicated in parentheses. Significance levels are denoted by *, **, and ***, corresponding to the 10%, 5%, and 1% probability levels, respectively. Chi-squared tests employed to assess the balance between model-adjusted means of covariates in the treatment and control groups across all covariates are reported in Table 11. The ATEs are estimated separately, not jointly, using jackknife estimation; that is, different regressions are conducted for each column. The Chi-squared tests are performed separately for each intervention.

Three hypotheses could explain this intriguing result. The first is that the examined intervention has a perverse effect, potentially encouraging households to specialize in pastoral activities at the expense of agricultural production. The second hypothesis is that the food habits of agro-pastoralist households have changed, with a substitution of animal-based foods for cereals. The third is the presence of significant measurement errors in calorie intake data. Examining these hypotheses, especially the first, is one of the aims of the next sub-sections.

4.2 Effects of interventions on pastoral profit and production levels

Table 3 reports the estimated average treatment effects of the selected interventions on the pastoral profit of households (link a in Figure 1) and the levels of cereal and milk production, all in logarithms.

Table 3: ATEs of interventions on household pastoral profit and production levels

	Log of annual profit from livestock activities	Log of annual quantity of milk production	Log of annual quantity of agricultural production
	ATE	ATE	ATE
Participation in extension services	0.312** (0.013)	0.555** (0.010)	0.202 (0.287)
Testing covariates balance (Chi-square test)	(0.347)	(0.684)	(0.342)
Number of Observations	595	326	482
Participation in veterinary services	0.163 (0.143)	0.818*** (0.004)	0.433** (0.022)
Testing covariates balance (Chi-square test)	(0.712)	(0.977)	(0.474)
Number of Observations	595	323	482
Participation in low-cost livestock feed	0.230* (0.071)	0.294 (0.240)	-0.255 (0.295)
Testing covariates balance (Chi-square test)	(0.767)	(0.99)	(0.65)
Number of Observations	585	318	472

Notes: This table presents the average treatment effects (ATEs) of the studied interventions (displayed in rows) on three outcomes: household pastoral profit, agricultural production levels, and milk production (shown in columns). We focus on the three main crops for agricultural production: millet, sorghum, and cowpea. The values in parentheses are p-values. Significance levels are denoted by *, **, and *** for the 10%, 5%, and 1% probability levels, respectively. Using Chi-squared tests, we assess whether the model-adjusted means of the covariates are the same between the treatment and control groups. The ATEs for household pastoral profit are estimated with jackknife estimation, while the ATEs for milk production and agricultural production are estimated using the 'teffects'command in Stata, due to the restricted samples for these outcomes.

Only veterinary services have a significant impact on the production levels of the three main agricultural products (millet, sorghum, and cowpea)[14]. Joint effects of interventions may occur in contrast with focusing on each intervention separately. However, only 9.6 percent of the considered households participate in both veterinary and extension services. Similarly, only 11 percent of these households participate in both low-cost feed and extension services. Figure 2 in Appendix A6 shows that the overlap between distinct interventions is limited in these data and cannot drive the results of this investigation.

Only extension services have a significant and positive effect on the annual profit of households from livestock activities. Participation in this program increases households' annual profit from livestock activities by 31.2 percent. The effects of other interventions are positive but not significant, except for participation in low-cost livestock feed, which is significant only at the 10 percent level.

Extension services are the only intervention that enhances pastoral profit among the considered interventions, partially due to their effect on milk production. However, this does not appear to

[14] Among the surveyed households, 85 percent produce at least one of these three agricultural products.

be the sole factor, with participation in veterinary services also associated with an increase in milk production. Extension services remain the only intervention achieving the objective of increasing pastoral profit. Let us investigate whether this positive effect is transmitted to dietary intake.

The positive effect of veterinary services on milk and cereal productions is noteworthy. It first suggests that this intervention is effective in preventing and mitigating losses caused by livestock diseases, which helps maintain or increase milk production, although it may not extend to meat production. Moreover, it points to a diversification strategy employed by these households, as a plausible response to livestock diseases. Some Tuareg herders in Niger switch to agriculture after experiencing livestock losses due to drought and disease (Le Point, 2019). This could be related to the effect of veterinary services on households' cereal production, if veterinary visits are correlated with livestock disease.

4.3 Effects of pastoral profit on dietary intake

As discussed, the effects of pastoral profit are estimated by running weighted linear 2SLS regressions, where the dietary intake measures serve as the dependent variables, and annual profit is an independent, potentially endogenous variable. The control variables X_i are the same as those used when modeling the total treatment effect on the outcome variables. The estimates of the mediation model (links a and c' in Figure 1) are reported only for extension services, as it is the only intervention that affects profit (see Table 4). The mediation models for the other two interventions are presented in Appendix A9.

As explained above, to assess the direct effect of each intervention, the treatment variable must be included in the second stage of the 2SLS regression. This also requires the inclusion of the treatment variable in the first stage, consistent with the correct formula for the 2SLS estimator. Including controls in the 2SLS estimation and applying weights improves the plausibility of not only the conditional independence of the treatment and the outcome but also the conditional independence of the instruments and the outcome.

With extension services, the exogeneity of the logarithm of profit is rejected at the five percent level or lower for all the dietary outcomes considered, except for calories from animal products. As a consequence, we estimate the model using weighted 2SLS regression for the dietary diversity score, total calorie intake, and calorie intake from cereals, and, following pre-test estimation approach, weighted OLS regression for calorie intake from animal products[15]. The test results for weak instruments using the Cragg-Donald Wald F-statistics suggest that our instruments are not weak. Nevertheless, we implemented the two-step weak IV methodology developed by Sun (2018), based on Andrews (2018), to compute identification-robust confidence sets.

The first-stage estimation results, reported in Panel B of Table 4, indicate that households living in clusters with a high incidence of livestock disease experienced higher annual pastoral profits. These households predominantly belong to the larger herder group, which may favor the increase in pastoral profit. Larger herds can act as a buffer against losses due to disease, as they are better able to absorb losses while maintaining overall productivity and income. This stability may also result from economies of scale in accessing veterinary services and managing diseases (Næss and Bårdsen, 2013). The coefficient of extension services in this equation is significant and is significantly different from that obtained when estimating the effect of extension services on profits

[15] Using 2SLS instead of OLS for the regression of calories from animal products does not alter the general results of this paper, which are based on total calorie intake. The less efficient 2SLS estimates for this regression are reported in the last column of Table 4.

using IPWRA (+36 percent with the weighted 2SLS model compared to +31 percent with IPWRA), which is reassuring.

In the second stage, the effect of a ten-percent increase in pastoral profit on households' dietary diversity is statistically significant and almost the same for the three intervention-specific mediation models, ranging from 3.4 to 4 percent (see Tables 4, 14 and 15), which is substantial. This impact is therefore relatively robust to the inclusion of any of the three intervention dummies.

In contrast, a ten-percent increase in profit diminishes total daily per capita calorie intake by -7.4 to -15.5 percent, depending on the intervention. However, the significant effect of profit differs depending on whether it is assessed on calories from cereals or animals. Increasing households' pastoral profit by 10 percent amounts to increasing their calorie intake from animals by 4.6 percent and lowering their calorie intake from cereals by 15 percent, on average, across all the interventions. These results align with policies altering agro-pastoralist households' dietary habits toward more diversified diets with higher calorie intakes from animal products. This transition may be driven by new incentives associated with increasing pastoral profit and greater specialization in pastoral activities. In Niger, the specialization of livestock activities can be accompanied by a significant change in the lifestyles of households. With chronic pasture deficits and water shortages due to frequent drought periods, these households can turn to pastoral transhumance in search of fresh pasture. This livelihood switch can induce households to consume easy-to-find calories from animal products instead of cereals that may become hard to come by. This contrast in the consumption pattern between nomadic and sedentary pastoralist or agro-pastoralist households was studied in northern Kenya by Fratkin and Roth (2006). According to these authors, a nomadic pastoral diet is characterized by calorie-poor and protein-rich foods, which is consistent with our findings.

Moreover, whether for pastoral or agro-pastoral households, those who engaged in pastoral mobility[16] the year before the survey differs from the others in terms of their mean dietary intake (see Table 8 in Section 5 of the Appendix). Those who engaged in pastoral mobility consume fewer calories, notably fewer from cereals, while they consume more calories from animals and enjoy higher dietary diversity than those who were not mobile. This supports our interpretation linking pastoral mobility and diet composition. In this case, a nutritionally harmful specialization of households in pastoral activities may contribute to explaining the negative impact of some agro-pastoral policies on total calorie intake. Without mobility, a switch in production from cereals to animal products allied to substantial consumption rates of own produce, as is often the case in Niger, may also explain this negative impact. Changes in food tastes or social influences may have similar effects, although they are less obvious to relate to income incentives of extension services[17].

At first glance, designing agro-pastoral policies to raise pastoral profit may seem like a good idea, supported by this mediator's significant indirect effects. Unfortunately, the direction of these indirect effects on dietary intake is probably not intended, with perverse negative consequences for total calories.

[16] Pastoral mobility refers to the movement of one or more household members with animals in search of pasture and water. It is a movement of people and animals from dry to wet areas with abundant pasture and water for animals

[17] Law et al. (2020) provide evidence of the declining importance of cereals in the diets of Indian households, attributing this shift to changing food preferences.

Table 4: Mediation model for extension services

	Panel A: Weighted 2SLS/OLS				
	Outcomes				
	Log of household dietary diversity score	**Log of total daily per capita calorie intake**	**Log of daily per capita calorie intake from cereals**	**Log of daily per capita calorie intake from animals (OLS)**	**Log of daily per capita calorie intake from animals (2SLS)**
Mediator					
Log of annual pastoral profit	0.362*** (0.010) [0.169, 0.837]	-1.551** (0.043) [-4.259, -0.644]	-2.102** (0.027) [-5.580, -0.994]	0.538*** (0.001)	0.229 (0.574)
Policy					
Participation in extension services	0.017 (0.773)	0.220 (0.444)	0.334 (0.342)	0.326 (0.117)	0.418* (0.077)
	Panel B: Weighted First Stage				
	Mediator				
	Log of annual pastoral profit				
Policy					
Participation in extension services	0.329*** (0.004)				
Instruments			-		
Livestock disease	0.552*** (0.000)			-	
Control variables	X	X	X	X	X
Test of exogeneity of log profit (Robust F: p-values):	[0.00]	[0.00]	[0.00]	[0.07]	[0.07]
F-Statistics for first-stage statistics for excluded instruments	12.31	12.31	12.31	-	7.87
Test for weak instruments: Craig-Donald Wald F statistics [Stock-Yogo Critical value at 15% maximal IV size]	16.189 [8.96]	16.189 [8.96]	16.189 [8.96]	-	9.898 [8.96]
R Square	-	-	-	0.16	-
Number of observations	595	595	595	595	595

Notes: This table reports the estimation results of the mediation model for participation in extension services. Panel A displays the second-stage results of the weighted two-stage least squares regression, highlighting the mediator's effect on the studied outcomes. For the "Log of daily per capita calorie intake from animal products" outcome, the mediator's impact is estimated using both weighted ordinary least squares and weighted 2SLS. The second row presents the direct effect of the policy on the outcomes. Panel B shows the first-stage results of the weighted 2SLS model, illustrating the impact of the policy and instruments on the mediator. Values in parentheses are p-values. Significance levels are denoted by *, **, and ***, representing 10%, 5%, and 1% levels, respectively. The test for weak instruments is implemented using the Cragg-Donald F-statistic. The identification-robust 95% confidence intervals for linear IV, calculated using the 'twostepweakiv' package by Sun (2018), are in brackets.

4.4 Direct and indirect effects of interventions on dietary intake

The estimated total, direct, and indirect effects of the considered interventions on dietary intake are summarized in Table 5. Livestock extension services are the only intervention that significantly impacts profits from livestock activities. Consequently, this is the only intervention for which decomposing the total effect is particularly relevant. All the indirect effects of extension services are significant for the four dietary intake indicators, though most only at the 10 percent level, except for calorie intake from animal products, where the indirect effect is significant at the 5 percent level.

The size of these effects varies across the four outcomes. The results indicate that the effect of extension services on the dietary diversity score mediated through profit is seven times greater than the direct effect, which occurs through channels other than pastoral profit. Furthermore, profit fully explains the unexpected negative effect of livestock extension services on calorie intake from cereals. While the direct effect on this outcome is positive and insignificant, it is insufficient to offset the negative indirect effect.

In addition, participation in low-cost livestock feed has a significant total and direct effect at the 1 percent level, as well as a marginally significant indirect effect at the 10 percent level, on calorie intake from animal products.

Table 5: Decomposition of the total effect of the interventions on dietary intake

		Outcomes			
		Log of household dietary diversity score	**Log of total daily per capita calorie intake**	**Log of daily per capita calorie intake from cereals**	**Log of daily per capita calorie intake from animals**
Participation in extension services	TE	0.123*** (0.000)	-0.375** (0.021)	-0.439** (0.01)	0.491** (0.019)
	IE	0.113* (0.050)	-0.484* (0.076)	-0.656* (0.059)	0.168** (0.026)
	DE	0.016 (0.77)	0.219 (0.444)	0.334 (0.342)	0.327 (0.117)
	TE=IE+DE	-0.006 (0.745)	-0.110 (0.146)	-0.117 (0.192)	-0.003 (0.958)
	∣IE∣ / ∣DE∣	7.06	2.21	1.96	0.51
Participation in veterinary services	TE	0.184*** (0.000)	-0.199 (0.100)	-0.272** (0.026)	0.420** (0.045)
	IE	0.066 (0.149)	-0.121 (0.219)	-0.202 (0.169)	0.068 (0.111)
	DE	0.036 (0.550)	-0.025 (0.891)	-0.011 (0.955)	0.378 (0.100)
	TE=IE+DE	0.081*** (0.005)	-0.052 (0.534)	-0.058 (0.576)	-0.025 (0.794)
	∣IE∣ / ∣DE∣	1.83	4.84	18.36	0.18
Participation in low-cost livestock feed	TE	0.230*** (0.000)	0.076 (0.555)	0.078 (0.565)	0.868*** (0.000)
	IE	0.077 (0.105)	-0.185 (0.184)	-0.284 (0.133)	0.099* (0.098)
	DE	0.154*** (0.004)	0.302 (0.108)	0.384 (0.106)	0.808*** (0.000)
	TE=IE+DE	-0.001 (0.939)	-0.039 (0.514)	-0.021 (0.770)	-0.040 (0.542)
	∣IE∣ / ∣DE∣	0.5	0.6	0.82	0.12

Notes: This table displays the results of the decomposition of the effects of the studied policies (reported in rows) on the outcomes (shown in columns). The total effect of each intervention is broken down into an indirect effect (i.e., the effect mediated through profit) and a direct effect (i.e., the effect channeled through other ways besides profit). TE= Total average treatment effect, IE= Indirect average treatment effect through the annual livestock profit, and DE= Direct average treatment effect. DE is the part of the total effect that does not operate through the annual livestock profit obtained in the mediation model. Values in parentheses are P-values. *, **, and *** indicate significant differences at the 10%, 5%, and 1% levels, respectively.

Extension services increase dietary diversity scores by 11 percent through their positive effect on profit. In addition, through profit, extension services decrease calorie intake from cereals by 66 percent, while raising calorie intake from animal sources by 17 percent. This amount to a decrease in total calorie intake by 48 percent.

Therefore, pastoral profit predominantly mediates the effect of extension services and veterinary services on pastoralists' dietary intake. This hints at the causes of the decline in calorie intake due to extension services. However, this intervention improved pastoralist profits and increased household dietary diversity.

In contrast, private veterinary services and low-cost livestock feed did not significantly improve pastoral profits, although their total effect on dietary diversity is significantly positive. Their indirect effect on dietary diversity is therefore non-significant and small, while only the direct effect of the low-cost livestock feed on dietary diversity is significant. Profit is not a good mediator of the effects of these two interventions, especially for the low-cost livestock feed.

Among plausible mechanisms for the feed subsidies' direct effects, the received livestock feed may not be used to feed animals, but sold or given to friends or relatives. Then, the obtained cash from these sales may be used to buy food products. Therefore, without increasing pastoral profit, the livestock feed program can enhance households' dietary intake by means of income or exchange.

The livestock extension services may facilitate household access to livestock products and input markets and better link the production of animal products and consumption through pastoral profits. However, given that calories are surely a normal good in this context, the effect of pastoral profit on reducing calorie consumption suggests rejecting separable agricultural household models when analyzing those households' behavior in favor of complex non-separable mechanisms involving lifestyle changes.

Finally, IPWRA estimates of average treatment effects of extension services on mobility and distance to the market, with inverse probability weighing, show that this policy significantly increases pastoral mobility (by 0.9) and the log of the distance to the nearest market (by 0.132). This supports our interpretation of induced pastoral specialization, and some transhumance, while not with distress sales that would rather have left distressed households stranded in their original location.

5 Conclusion

This paper investigated three national agro-pastoral interventions on household dietary intakes from the major policy program PRAPS & PASEL in Niger (livestock extension services, veterinary services, and subsidies for low-cost livestock feed). Did these interventions generate higher pastoral profit and better dietary intakes? Were the latter because increased income was used for better nutrition or due to alternative channels? To answer these questions, we estimated and decomposed the average treatment effect of each of these policies into an indirect effect that passes through the pastoral profit and a residual direct effect channeled through other factors.

Based on a national agro-pastoral survey conducted in 2016 in Niger, we bring new evidence on links between agriculture and nutrition. Our results evince a diversity of effects of these interventions on diet diversity and calories. In particular, livestock extension services, which are found to exclusively operate through increased pastoral profit in this case, deplete caloric intake even though they improve diet diversity. In contrast, private veterinary services and low-cost livestock feed programs affect neither profit nor calories (whether through direct or indirect effects) – two cases of quasi-failing policies-, although they still improve diet diversity. Still, a significant total and direct effects of low-cost livestock feed emerge for calorie intake from animal products.

The analysis has revealed that extension services can damage households' calorie intake. By raising pastoral profit, extension services foster pecuniary incentives for the specialization of households in pastoral activities, sometimes even pushing them toward transhumance. This lifestyle change reduces their calorie consumption since most calories come from cereals that they no longer choose to produce or can less easily access.

Overall, the estimation results show, in Niger, that interventions primarily designed to raise pastoral incomes significantly enhance household dietary diversity, and sometimes calorie intake from animals for Nigerien pastoralists. However, they may also severely deplete their calorie intake from cereals. To avoid this perverse consequence noxious to nutrition, policy designers should better account for agro-pastoralists access to cereal markets and monitor whether policies generate differentiated incentives in favor of specific specializations or lifestyles. Other potentially adverse policy effects not examined in this study include damage to pastoral ecosystems caused by the expansion of pastoral activities in areas where the land's capacity to support additional grazing is limited.

The significant effects of extension services are found exclusively through pastoral profit, which points out the strategic importance of this variable for this intervention. Therefore, policymakers should investigate the profit-enhancing mechanisms of extension services to make them more effective. They should also examine why direct effects (e.g., through social networks or market functioning) are not more present.

Of course, findings depend on assumptions, especially those related to measurement errors in calorie intake data and pastoral profit indicators, even though distress sales were rejected. The typical assumption is that these measurement errors are additive and random, although this assumption may be strong. Another limitation to statistical mediation analysis in this case is the possible confusion between changes in production technology and changes in unobserved inputs. Finally, exploiting cross-sectional observational data relies on an ignorability condition, which cannot be tested and may be strong, even though there are time lags between interventions and outcomes. Still, even if average treatment effects estimates may include biases, they are the only feasible in this case, and it is not clear that these biases are necessarily large, particularly thanks to the double robustness of the used estimators. To the least, the obtained results have elicited new theoretical hypotheses to test the effects of policies and their interaction with activity and lifestyle choices.

However, these limitations suggest extending the investigation with data from more intensive surveys, particularly those following households over multiple years, to get more accurate measures of medium-term pastoral profit. Finally, based on richer data, future research should extend to other agricultural mediator variables than pastoral profit, and assess other channels through which policies may affect household dietary intake, such as observable changes in activity specialization.

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Appendix

A1 The 3N initiative and the PRAPS and PASEL programs

The Initiative 3N (i3N) addresses the urgent issues of food and nutritional security in Niger. At the heart of this strategy lies the enhancement of agricultural and pastoral outputs. This is achieved by adopting advanced agricultural techniques, effective forestry management, and improved pastoral practices, all aimed at increasing production and thereby agro-pastoral profit. The i3N prioritizes universal access to food, addressing the underlying socio-economic impediments that hinder a significant portion of the population from meeting their fundamental nutritional requirements. However, mere availability of food doesn't guarantee its optimal nutritional use. Then, the i3N also develops educational initiatives and awareness campaigns to advocate for healthier dietary choices and to address the root causes of malnutrition. The strategy gives particular attention to the livestock sector, recognizing its dual role as both a dietary mainstay and a primary income source for numerous Nigeriens. To support this sector, i3N has delineated specific interventions, such as the development of water infrastructure tailored for livestock, the enhancement of veterinary services and training, and research programs focused on breeding livestock resilient to the extreme conditions of the Sahel. The three interventions studied in this paper are at the core of this strategy within the PRAPS and PASEL programs.

A2 Population of interest

We focus on households that own sheep and cattle. Indeed, only the information collected on this group of households is complete enough for econometric analyses. For example, these are the only households for whom we have data on livestock prices, costs, and production levels. Another reason to focus on these pastoral and agro-pastoral households is that agro-pastoral interventions should not directly affect households with no pastoral activity, which are not targeted. In our initial sample, some households do not own cattle or sheep and are therefore not intended targets of the studied interventions. Instead, they may own goats, poultry, donkeys, camels, or even no animals at all. These households are often peri-urban households little concerned by pastoral policies. When we exclude these households, after cleaning the data and removing a few outliers, this leaves us with 600 household observations.

A3 Measurement issues and outliers

Large outliers seem to be related to ceremonies and food stock. We checked that these outliers are not systematically linked to the absence of policy access. Finally, on average, almost 83 percent of calorie intake comes from cereals, and only 4.4 percent strictly comes from animal food products. It may be that calorie intake from animal products has not been fully recorded due to the 3 months recall period for consumption. However, this pattern is consistent with the literature on pastoral households that show that few calories come from animal products. Moreover, the large values observed in the household calorie consumption data are not necessarily irrelevant outliers. Detecting outliers can be based on boxplots. However, the distribution of these variables is skewed and long-tailed, which makes the standard boxplot method ineffective, as Bruffaerts et al. (2014) pointed out. Instead, we used the generalized boxplot method, proposed by these authors, which addresses these data characteristics (see also Verardi and Vermandele (2018)) and yields a smaller set of outliers for removal.

A4 Construction of variables

We construct two distinct outcome variables: dietary intake indicators and households' profit from livestock activity. The three treatment variables correspond to the policies selected for this study. A dummy variable describes each treatment, equal to 1 when the household reported participating in the policy and 0 otherwise.

A4.1 Dietary intake indicators

In assessing Nigerien household dietary intake, our selection of indicators—namely, dietary diversity score, total caloric intake, caloric intake from cereals, and from animal food products—was grounded in the established nutritional and economic literature. The dietary diversity score serves as a proxy for micronutrient adequacy, with a higher score often associated with better health outcomes and greater resilience against malnutrition. Total caloric intake provides a fundamental measure of energy consumption, essential for gauging the basic nutritional status of households. The specific focus on calories from cereals and animal food products reflects the primary dietary sources in Niger, allowing for an explicit role for pastoral products, especially milk. Together, these indicators offer a contextually relevant overview of nutrition intake.

The *dietary diversity score* records how many food groups had been consumed by the household over a given reference period and is a good proxy for diet quality. Following the FAO, 12 food groups compute the *dietary diversity score* (Swindale and Bilinsky, 2006). Table 6 shows the food products consumed by households categorized into 12 groups.

Table 6: Classification of food products

Food group	**Specific Food Product (from survey)**
A. Cereals	Millet, sorghum, bread, maize, edible pasta
B. Roots and tubers	-
C. Vegetables	Condiments, okra
D. Fruits	-
E. Meat, poultry, offal	Meat, poultry
F. Eggs	-
G. Fish and seafood	Fish,
H. Pulses/legumes/nuts	Cowpea, sesame seeds, groundnuts
I. Milk and milk products	Fresh milk, curdled milk, cheese
J. Oils/Fats	Oil, butter
K. Sugar/honey	Sugar
L. Miscellaneous	Tea

Notes: Classification made by the authors using the food groups proposed by the FAO.

If the household reported that, over the last quarter, it consumed at least one of the food products belonging to a specific food group, an index value of 1 is attributed to this household for the corresponding food group and 0 otherwise. As seen from Table 1, none of the foods consumed by the surveyed households belong to the food groups of roots and tubers, fruits, or eggs. This is because the survey did not record any consumption of these food groups due to their low frequency among agro-pastoralists[18]. Finally, a *dietary diversity score* is computed for each surveyed household as the total unweighted number of food groups consumed by the household.

For agro-pastoral households in Niger, dietary diversity should play a pivotal role in determining overall nutrition outcomes. In particular, pastoral communities, inherently mobile and reliant on livestock for livelihood, often face unique dietary challenges compared to their agrarian counterparts. While their diets might be rich in animal proteins—sourced mainly from milk, meat, and, occasionally, blood—there are potentially deficient in essential micronutrients commonly derived from plant-based foods. This limited dietary diversity can lead to malnourishment, particularly when pastoral households cannot trade or access markets to diversify their food intake.

To illustrate the variation in dietary patterns, we compare the mean diets of the first and the last quartiles of the diversity score. In the lowest quartile, all households consume cereals, especially millet, 41 percent of them drink milk, and 35 percent eat some vegetables. The other food categories are consumed by only few households in this quartile (for example, only 15 percent eat meat). In contrast, in the fourth quartile, all households consume not only cereals, but also vegetable, fat, sugar and meat. The other food groups, apart from fish, are also consumed by almost all households in this quartile, i.e. pulses (97 percent), milk (99 percent) and miscellaneous (97 percent). Therefore, in this country, increasing nutritional diversity means to give up a restrictive diet concentrated on millet, milk and some vegetables, to extend it to almost all other food products. This is feasible only through access to food markets.

A4.2 Daily calorie intake per capita

The *daily calorie intake per capita* for each household is computed by converting the recorded food quantities consumed by the household into calories. For this, we use the food composition table provided by the FAO for West Africa in 2012 (Stadlmayr et al., 2012). We separately computed calorie intake from cereals (millet, sorghum, bread, maize, and edible pasta) and animal food products (meat, poultry, fish, fresh milk, curdled milk, and cheese).

A4.3 Profits from livestock activity

The last outcome variable is the household annual pastoral profit. Our empirical strategy is based on only three outputs: cattle, sheep, and milk production (fresh milk and curd milk), corresponding to the most accurately measured information. Although a few residual items are neglected (e.g., chicken), this approach avoids too high heterogeneity of items that would substantially raise the noise from measurement errors and erroneous or inaccurate conversion into TLUs. For cattle and sheep, we used the animals sold and slaughtered by the household as a measure of output because stock variations are unobserved. For milk, we used total household production. There is no data on stock variation for milk products between the two years.

All these production measures were valued at the market prices[19] faced by each household individually. The total of these production values amounts to the gross income of the households from pastoral activity.

[18]In addition to the low-frequency issue, the quarterly retrospective questionnaire that has been employed for the survey is likely to generate omissions and thereby lead to underestimated dietary scores.

[19]The cattle and sheep prices are given by animal sex and age. For animals directly consumed by the households, we compute an average price per TLU using these market prices.

In assessing pastoral production costs, we identified four key monetary expenditures: i) herd health costs, which include veterinary services, vaccinations, and medicines; ii) water consumption, which encompasses the costs of sourcing, storage, and provision; ii) feed consumption, covering expenses for fodder, grains, and supplements; and iv) labor costs, factoring in wages for shepherds and fees for market intermediaries during sales. Surveyed households provided cost data for their entire herd. Restricted profit is derived by deducting these observed costs from gross pastoral income. Any unaccounted costs or benefits were excluded due to lack of observation.

A4.4 Pastoral profit and distress sales

As many as 44 percent of households in the higher quartile of pastoral profit have stated that they had frequently suffered from animal illnesses. This could be consistent with distress sales which would explain the high profit level. No other blatant hints about distress sales have been found by examining cross tables of diverse economic variables with pastoral profit. Low-profit households rarely own many animals. For example, only about one-twentieth of households in the first quartile of profit are in the fourth quartile of the numbers of cattle (or sheep). More importantly, only 15 percent (respectively 11 percent) of households in the fourth quartile of profit are in the first (respectively, second) quartile of the number of sheep.

Additional descriptive statistics show that distress sales, if they exist, remain marginal in these data. For example, lack of pasturage or water shocks are not correlated at all with higher profit. Besides, almost two-thirds of households have not sold any cattle (the same applies to sheep). On the whole, households belonging to the 'small herder category' have sold fewer animals while households in the 'large herder category' have sold more. This is reassuring since small producers should be much more likely of distress sales. When examining the 44 percent of high-profit households that suffered from frequent animal illnesses, it is found that they are almost equally distributed among per capita consumption quartiles (slightly more in the top two quartiles that regroup 56 percent of these households), in contrast with what would have been expected with distress sales affecting more the poorest households. Moreover, these potentially problematic households only represent 10.8 percent of the sample, which looks rather marginal.

In addition, t-tests were conducted to compare own-produced consumption rates between households treated and not treated by extension services. The results indicate that the hypothesis of equal overall consumption rates is not rejected at any reasonable statistical level. However, when focusing specifically on milk, the hypothesis is rejected at the one percent level, favoring the treated group. This suggests that the intervention encourages specialization with higher levels of own-produced milk consumption, rather than inducing distress sales that would typically result in lower overall own-produced consumption rates, as distress sales generate cash likely spent on various food items.

Measurement errors in profit could also arise from investment in livestock that yield benefits over multiple years. We acknowledge this limitation of the annual profit measures, consistent with the majority of studies in the literature, which often lack long-term panel data on livestock and the associated costs and benefits of these activities.

A5 Outcome dietary intake comparison for each intervention

As shown in Table 7, the outcomes of households participating in an intervention generally differ from those that do not. Households participating in extension services have a calorie intake level that is 42 percent lower than those not participating. However, their dietary diversity score is 14 percent higher than that of non-participating households. They also consume more animal-based food products and fewer cereals compared to households not participating in extension services.

Households participating in low-cost livestock feed or private veterinary services have a higher dietary diversity score and consume more animal-based food products and fewer cereals than non-participating households. Regarding annual profit from livestock production, for all three interventions, households that participated are better off than those that did not. These data provide evidence supporting the analysis that was conducted.

Table 7: Comparison of households outcomes based on their participation in the interventions

		Log of household dietary diversity score	**Log of total daily per capita calorie intake**	**Log of daily per capita calorie intake from cereals**	**Log of daily per capita calorie intake from animals**	**Log of annual pastoral profit**
Participation in extension services	Participation	1.72	7.38	7.07	3.72	14.96
		(.02)	(.14)	(.15)	(.19)	(.09)
	No Participation	1.58	7.81	7.56	3.26	14.69
		(.02)	(.05)	(.06)	(.09)	(.05)
	Diff	.14***	-.42***	-.50***	.467**	.26***
		(.04)	(.14)	(.14)	(.20)	(.10)
Participation in veterinary services	Participation	1.76	7.54	7.22	3.66	14.83
		(.03)	(.10)	(.10)	(.18)	(.08)
	No Participation	1.57	7.77	7.53	3.27	14.73
		(.02)	(.06)	(.06)	(.08)	(.05)
	Diff	.19***	-.23*	-.30**	.388**	.10
		(.04)	(.14)	(.14)	(.20)	(.10)
Participation nin low-cost livestock feed	Participation	1.80	7.77	7.52	4.01	14.94
		(.02)	(.12)	(.12)	(.18)	(.11)
	No Participation	1.57	7.71	7.46	3.23	14.71
		(.02)	(.06)	(.06)	(.09)	(.04)
	Diff	.23**	.05	.06	.78***	.23**
		(.12)	(.15)	(.16)	(.23)	(.12)

Notes: This table compares the mean values of outcomes (in columns) for households participating, and not, in specific interventions (in rows). Values in parentheses represent standard errors. *, **, and *** indicate significance at the 10%, 5%, and 1% probability levels, respectively, for the 'Diff' column that shows the mean difference in outcome variables between households that participate in an intervention and those that do not.

Table 8: **Comparison of pastoral and agropastoral household dietary intake across pastoral mobility**

		Log of household dietary diversity score	Log of total daily per capita calorie intake	Log of daily per capita calorie intake from cereals	Log of daily per capita calorie intake from animals	Log of annual pastoral profit
Agropastoral households (N=557)	No Pastoral Mobility (N=444)	1.570 (.021)	7.728 (.062)	7.495 (.063)	3.277 (.091)	14.606 (.048)
	Pastoral Mobility (N=113)	1.704 (.030)	7.389 (.136)	7.050 (.147)	3.431 (.183)	15.001 (.080)
	Diff	-.133*** (.045)	.339*** (.141)	.445*** (.146)	-.154 (.208)	-.395*** (.103)
Pastoral households (N=43)	No Pastoral Mobility (N=23)	1.628 (.056)	9.203 (.072)	9.030 (.077)	2.696 (.451)	15.067 (.135)
	Pastoral Mobility (N=20)	1.963 (.033)	7.900 (.185)	7.414 (.152)	5.404 (.487)	16.181 (.282)
	Diff	-.335*** (.068)	1.302*** (.189)	1.616*** (.164)	-2.707*** (.527)	-1.114*** (.300)

Notes: This table compares the mean values of outcomes (in columns) for agro-pastoral households and pastoral households, both with and without mobility (in rows). Values in parentheses are standard errors. *, **, and *** indicate significance at the 10%, 5%, and 1% probability levels, respectively. The 'Diff' column shows the mean difference in outcome variables between households without pastoral mobility and those with pastoral mobility. The pastoral mobility is a dummy variable, with a value of 1 if any members of households were engaged in mobility to search for water and pasture last year, and 0 otherwise.

As shown in Table 9, households' assessment depends on where they live. Indeed, households in the South have easier physical access to livestock extension services than those in the North. The proportion of households that can access this intervention and that considered it easily accessible is significantly higher for households in the South than those in the North. However, the opposite situation is observed for veterinary services, with easier access in the North than in the South. There is no significant difference between the North and the South regarding households' cost evaluations of these interventions. Only the cost of low-cost livestock feed is significantly cheaper in the South than in the North.

Table 9: Mean households' assessment of access to interventions

Assessed aspects	Policies	North (N=239)	South (N=361)	Difference
Physical accessibility (1 if easy and 0 otherwise)	Access to extension services	.555 (.082) [36]	.734 (.048) [83]	-.179** (.095)
	Access to veterinary services	.753 (.051) [69]	.615 (.067) [52]	.138* (.085)
	Access to low-cost livestock feed	.512 (.080) [39]	.480 (.069) [52]	.032 (.105)
Cost (1 if less expensive and 0 otherwise)	Access to extension services	.805 (.065)	.807 (.043)	-.001 (.078)
	Access to veterinary services	.536 (.060)	.480 (.069)	.055 (.091)
	Access to low-cost livestock feed	.871 (.053)	.961 (.026)	-.089* (.059)
Quality (1 if good and 0 otherwise)	Access to extension services	.666 (.078)	.795 (.044)	-.128* (.090)
	Access to veterinary services	.840 (.044)	.423 (.068)	.417*** (.081)
	Access to low-cost livestock feed	.871 (.053)	.826 (.052)	.044 (.074)

Notes: This table presents the qualitative assessment of the interventions (in rows) by the surveyed households. This evaluation focuses on physical accessibility, cost, and quality. The statistics in this table are first the averages for each aspect of the assessed interventions, broken down by region. Values in brackets are the number of households that used the intervention. Values in parentheses are standard errors. *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Finally, the households' quality assessment is more positive in the South than in the North for livestock extension services, while the opposite result is obtained for private veterinary services. Assuming, for a moment, that these assessments can be generalized to households that have not had access to these interventions, these assessments of physical accessibility and cost of service could be interpreted as factors influencing participation. Unfortunately, this information is too censored to be used directly in our estimates. However, including a dummy variable for the households' region of residence (North or South) in our estimation allows us to incorporate part of this information.

A6 Jointly Examining the effects of the interventions

We evaluate the effects of the three interventions separately because each was originally designed to address a specific problem. Depending on its needs, a household may decide to participate in different interventions at different times or not at all. For example, a household may participate in veterinary services during the dry-and-wet season, a period conducive to the development of livestock diseases. However, during the dry-and-hot season[20], it might choose to use the low-cost livestock feed program due to the scarcity of pastureland during this season.

Thus, the effect of veterinary services may have already been observed before the household decides to participate in the low-cost livestock feed program. In this context, the household's decision to participate in the low-cost livestock feed program is not dependent on its prior participation in veterinary services. Evaluating the simultaneous effects of the three interventions is not relevant in this setting because the survey does not provide information on the precise timing of the household's access to each intervention. Moreover, as mentioned, a household's participation in one intervention may be independent of its participation in another. Therefore, we assess the impact of each intervention separately.

Figure 2 below shows the frequencies of different cases of overlap in participation across the interventions. About two-thirds of the households considered participate in only one intervention, further supporting the argument for evaluating the interventions separately.

[20]The dry-and-hot season corresponds to the period from February to May, while the dry-and-wet season corresponds to the period from October to January.

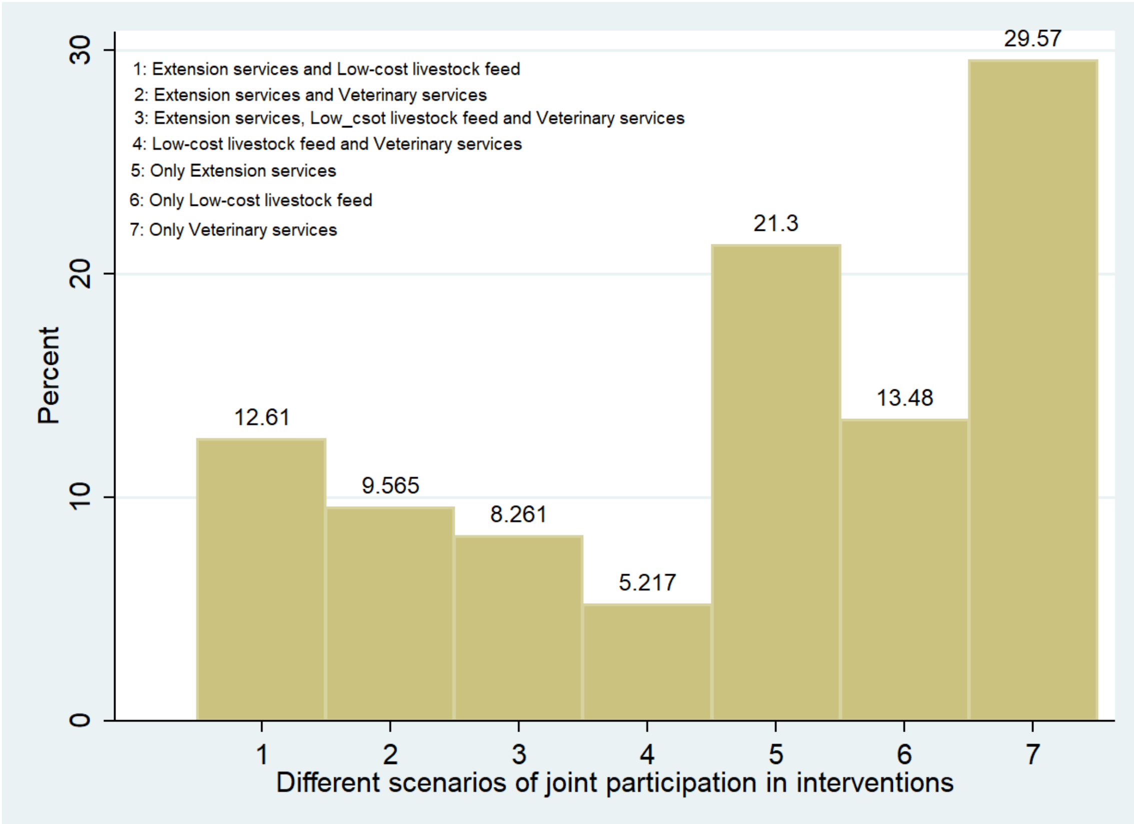

Figure 2: Distribution of households that have access to at least one policy among the three studied

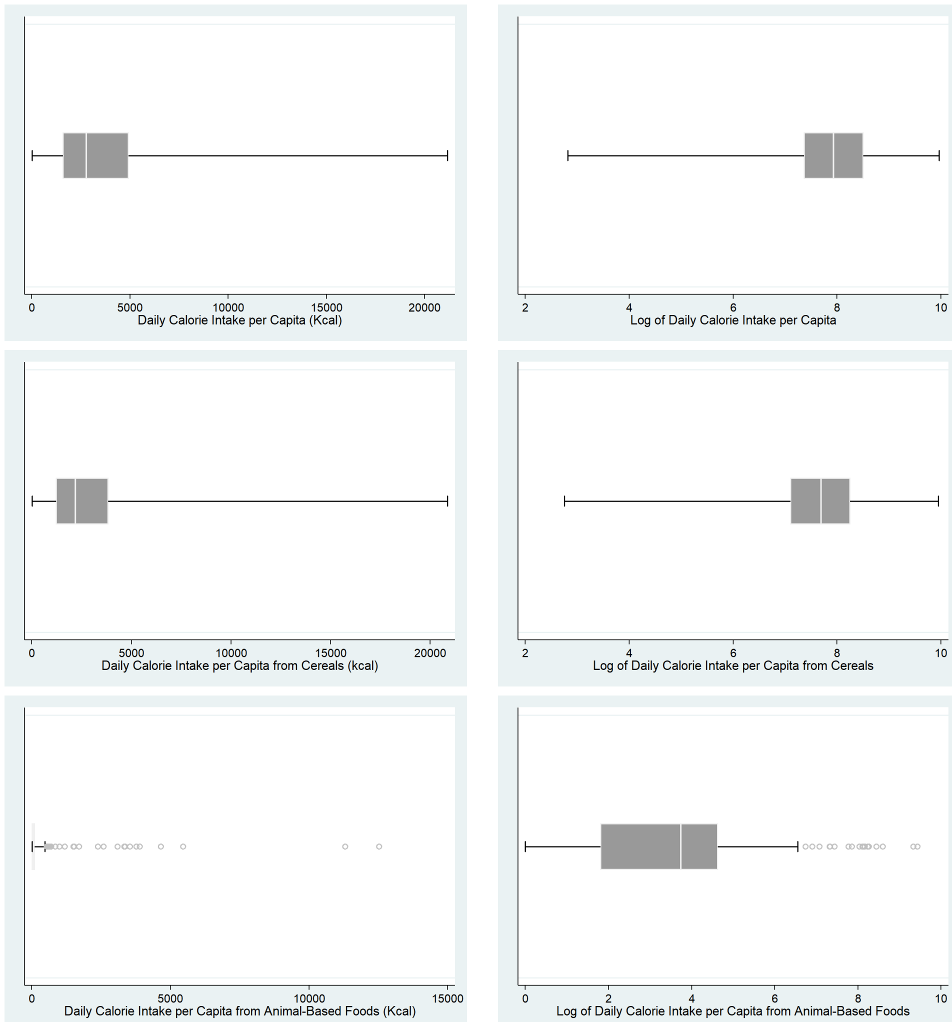

Figure 3: **Generalized boxplots of calorie intake**

Notes: Figure 3 presents generalized box plots for both the log-transformed and the level caloric intake values to identify potential outliers. The generalized boxplot, a refined data visualization technique, is particularly suited for representing skewed and heavy-tailed data distributions. In the generalized boxplot, whiskers are calculated based on the interquartile range (IQR). Typically, the lower whisker extends to the smallest data value that is larger than $Q1 - 1.5 \times \text{IQR}$, and the upper whisker extends to the largest data value that is smaller than $Q3 + 1.5 \times \text{IQR}$, where $Q1$ and $Q3$ are the first and third quartiles, respectively. However, the generalized boxplot adjusts these whiskers based on data skewness. Doing so effectively conveys the distribution of the central half of data through the box and the overall data spread via the adjusted whiskers. Outliers are defined as data points that lie outside these whiskers.

A7 Comparison of the control and treated groups based on the covariates used in the IPWRA model

Table 10: Baseline comparison

	Interventions					
	Use of extension services		Use of veterinary services		Use of low-cost livestock feed	
	Control	Treated	Control	Treated	Control	Treated
	(N=477)	(N=119)	(N=475)	(N=121)	(N=505)	(N=91)
Covariates for IPWRA (mean values)						
Sex of household head (1 if female)	.054	.025	.054	.024	.053	.021
	(.051)	(.024)	(.05)	(.02)	(.050)	(.021)
Age of household head (in years)	44.92	44.14	44.97	43.95	44.40	46.78
	(218.47)	(203.19)	(220.45)	(195.28)	(214.57)	(216.12)
Area of living (1 if in the South)	.58	.69	.648	.43	.61	.57
	(.24)	(.21)	(.22)	(.25)	(.24)	(.25)
Proportion of children (0-3 years old)	.10	.12	.10	.13	.11	.11
	(.02)	(.02)	(.01)	(.01)	(.01)	(.01)
Proportion of children (4-10 years old)	.25	.27	.25	.29	.25	.29
	(.03)	(.02)	(.03)	(.03)	(.03)	(.03)
Proportion of youths (11-16 years old)	.10	.12	.10	.12	.11	.11
	(.01)	(.02)	(.01)	(.02)	(.01)	(.01)
Proportion of young adults (17-20 years old)	.12	.11	.12	.10	.12	.09
	(.02)	(.02)	(.02)	(.01)	(.02)	(.01)
Ethnic group						
- Tuareg (1 if yes and 0 otherwise)	.24	.20	.21	.29	.22	.28
	(.18)	(.16)	(.17)	(.21)	(.17)	(.20)
- Fulani (1 if yes and 0 otherwise)	.53	.62	.60	.35	.55	.56
	(.25)	(.24)	(.24)	(.23)	(.25)	(.25)
- Haussa (1 if yes and 0 otherwise)	.15	.10	.14	.14	.15	.08
	(.13)	(.09)	(.12)	(.12)	(.13)	(.08)
Instruction level of household head						
- None (1 if yes and 0 otherwise)	.95	.94	.95	.92	.94	.94
	(.05)	(.06)	(.04)	(.06)	(.04)	(.05)
- Primary (1 if yes and 0 otherwise)	.03	.04	.03	.04	.03	.04
	(.04)	(.04)	(.03)	(.04)	(.03)	(.04)
Access indicator	.55	.70	.52	.66	.49	.61
	(.07)	(.05)	(.04)	(.03)	(.05)	(.03)

Notes: This table displays the average values, for both the control and treated groups for each intervention (in columns), of the covariates (in rows) used in the IPWRA model to estimate the effects of the interventions. Values in parentheses are variances.

Table 11: Characteristics of the control and treatment groups after IPWRA weighting

	Interventions					
	Use of extension services		Use of veterinary services		Use of low-cost livestock feed	
	Raw std difference	Weighted std difference	Raw std difference	Weighted std difference	Raw std difference	Weighted std difference
Covariates for IPWRA (mean values)						
Sex of household head (1 if female)	-.15	.04	-.15	-.08	-.17	-.07
	(.48)	(1.16)	(.47)	(.67)	(.42)	(.72)
Age of household head (in years)	-.05	-.07	-.07	.002	.16	-.07
	(.93)	(.94)	(.88)	(.80)	(1.00)	(.92)
Area of living (1 if in the South)	.24	-.01	-.44	.091	-.07	-.02
	(.87)	(1.00)	(1.08)	(.94)	(1.03)	(1.00)
Proportion of children (0-3 years old)	.08	-.006	.24	-.11	.02	.07
	(1.07)	(1.09)	(1.01)	(.84)	(1.08)	(1.04)
Proportion of children (4-10 years old)	.13	.06	.21	-.05	.24	-.03
	(.86)	(1.01)	(.81)	(.86)	(.98)	(1.09)
Proportion of youths (11-16 years old)	.15	-.07	.16	.12	-.004	-.09
	(1.26)	(1.11)	(1.21)	(1.07)	(1.07)	(1.04)
Proportion of young adults (17-20 years old)	-.08	.008	-.12	-.18	-.21	.02
	(1.03)	(1.19)	(.62)	(.61)	(.65)	(.84)
Ethnic group						
- Tuareg (1 if yes and 0 otherwise)	-.095	-.108	.16	-.02	.16	-.02
	(.88)	(.85)	(1.20)	(.97)	(1.22)	(.98)
- Fulani (1 if yes and 0 otherwise)	.18	.02	-.52	.07	.02	-.03
	(.95)	(.99)	(.95)	(.98)	(1.00)	(1.00)
- Haussa (1 if yes and 0 otherwise)	-.15	.056	-.002	-.07	-.20	.08
	(.71)	(1.11)	(1.00)	(.85)	(.63)	(1.16)
Instruction level of household head						
- None (1 if yes and 0 otherwise)	-.03	-.12	-.11	.02	.04	-.23
	(1.16)	(1.50)	(1.56)	(.90)	(.86)	(2.04)
- Primary (1 if yes and 0 otherwise)	.02	.12	.01	-.02	-.03	.26
	(1.11)	(1.67)	(1.09)	(.90)	(.88)	(2.55)
Access indicator	.61	.11	.76	-.14	.56	.05
	(.69)	(.68)	(.75)	(1.26)	(.60)	(.77)

Notes: Std = Standardized. This table presents the standardized differences between the control and treatment groups before (raw) and after IPWRA weighting. The differences become relatively small after the weighting procedure, indicating an effective balance between groups. Values in parentheses are variance ratios.

Table 12: Probit estimations of the participation in the interventions

	Participation in extension services	Participation in veterinary services	Participation in low-cost livestock fedd
Sex of household head (1 if female)	-0.663*	-0.559	-0.685*
	(0.348)	(0.370)	(0.388)
Age of household head(in years)	0.000	0.004	0.011**
	(0.005)	(0.005)	(0.005)
Area of living (1 if in the South)	0.083	-0.452***	-0.066
	(0.147)	(0.140)	(0.145)
Proportion of children(0-3 years old)	0.775	1.296**	0.312
	(0.580)	(0.606)	(0.606)
Proportion of children(4-10 years old)	0.730*	1.268***	0.713
	(0.443)	(0.461)	(0.454)
Proportion of youths(11-16 years old)	1.356**	1.505**	0.385
	(0.550)	(0.589)	(0.586)
Proportion of young adults(17-20 years old)	0.092	0.413	-0.289
	(0.546)	(0.584)	(0.598)
Tuareg (1 if yes and 0 otherwise)	0.154	-0.705***	0.274
	(0.255)	(0.247)	(0.276)
Fulani(1 if yes and 0 otherwise)	0.116	-1.008***	0.173
	(0.236)	(0.238)	(0.263)
Haussa(1 if yes and 0 otherwise)	-0.283	-0.911***	-0.302
	(0.284)	(0.272)	(0.320)
Instruction level of household is none	-0.229	-0.461	0.252
	(0.491)	(0.501)	(0.635)
Instruction level of household is primary	0.154	-0.308	0.619
	(0.573)	(0.594)	(0.718)
Access indicator for extension services	1.393***		
	(0.275)		
Access indicator for veterinary services		2.242***	
		(0.362)	
Access indicator for low-cost livestock feed			1.578***
			(0.333)
Constant	-2.050***	-1.476**	-2.947***
	(0.644)	(0.676)	(0.800)
Observations	596	596	586

Notes: The table reports probit regression coefficients with standard errors in parentheses. The dependent variables are binary indicators of participation in the respective interventions. The covariates include household head characteristics, demographic composition, ethnicity, education level, and access indicators for the interventions. Significance levels are denoted by * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$.

Table 13: Probit estimations of the accessibility to the interventions at the cluster level

	Dummy extension services	Dummy veterinary services	Dummy low-cost livestok feed
Population	0.0221***	0.0130***	0.0187***
	(0.00549)	(0.00462)	(0.00494)
Proportion of large producer		2.189***	1.154*
		(0.701)	(0.591)
Distance to veterinary health center	-0.0238***	-0.0118**	-0.0154**
	(0.00772)	(0.00566)	(0.00679)
Distance to a local veterinary services		0.0120*	
		(0.00626)	
The cluster is a village		0.552*	
		(0.311)	
Proportion of small producer	-1.205**		
	(0.530)		
Distance to the livestock feed bank	0.0285**		
	(0.0136)		
Z-score NDVI 2016			-0.542***
			(0.186)
Constant	-0.307	-1.332***	-0.743**
	(0.458)	(0.490)	(0.315)
Observations	92	92	90

Notes: The table presents probit regression coefficients with standard errors in parentheses, assessing the accessibility of interventions at the cluster level. The dependent variables are binary indicators representing the presence of an intervention within a cluster, taking the value 1 if at least one household participates in the intervention and 0 if no households participate. Covariates include cluster population, the proportion of large and small producers, and whether the cluster is classified as a village. Additional covariates include distances to veterinary health centers, local veterinary services, and livestock feed sources, as derived from the 2014 National Survey on Household Living Conditions and Agriculture in Niger by the World Bank. The Standardized Normalized Difference Vegetation Index (NDVI) for 2016 at the cluster level, sourced from the World Food Program, is also included. Predicted probabilities from these probit estimations serve as propensity scores at the cluster level for access to each intervention, utilized as access indicators. These indicators are employed as covariates in the treatment model of the IPWRA method to estimate Average Treatment Effects (ATEs). Significance levels are denoted by * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$.

A8 Common Support assumption

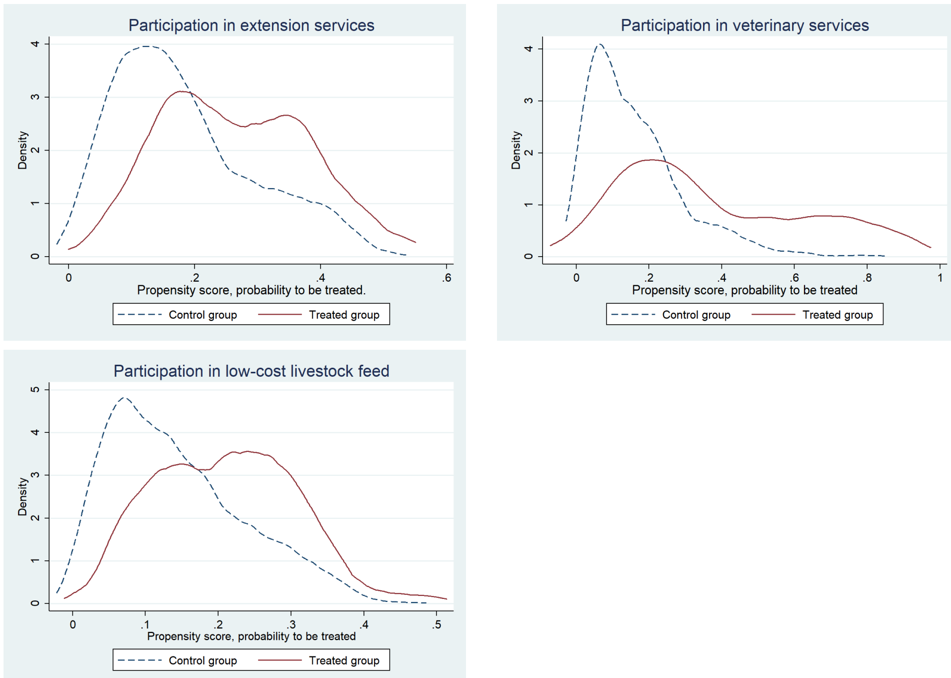

Figure 4: **Common Support assumption**

Notes: Figure 4 presents the density distributions of propensity scores (represented on the x-axis) for both the treatment and control groups across each of the three interventions. The propensity score, $\Phi(X_i'\hat{\lambda})$, represents the probability of a household receiving treatment based on its characteristics. The x-axis spans the range from the minimum to the maximum estimated probabilities for each intervention. Kernel density plots (using the Epanechnikov kernel) display the estimated propensity score distributions and validate the overlap assumption. This overlap allows for meaningful comparisons between the treatment and control groups. The estimated a priori probabilities of being exclusively in a specific group (i.e., at values 0 and 1) are negligible. The spikes observed in these plots reflect the prominence of household composition variables and the clustering of many households with similar demographic compositions.

A9 Decomposition of the total effect of private veterinary services and low-cost livestock feed on dietary intake

Table 14: Mediation model for private veterinary services

	Panel A: 2SLS/OLS			
	Outcomes			
	Log of household dietary diversity score	**Log of total daily per capita calorie intake**	**Log of daily per capita calorie intake from cereals**	**Log of daily per capita calorie intake from animals (OLS)**
Mediator				
Log of annual pastoral profit	0.408*** (0.003) [0.223, 0.766]	-0.739* (0.086) [-1.802, -0.086]	-1.234** (0.024) [-2.732, -0.529]	0.415** (0.027)
Policy				
Access to veterinary services	0.036 (0.550)	-0.025 (0.891)	-0.011 (0.955)	0.378 (0.100)
	Panel B: First Stage			
	Mediator			
	Log of annual pastoral profit			
Policy				
Access to veterinary services	0.144 (0.172)			
Instruments				
Livestock disease	0.596*** (0.000)			
Control variables	**X**	**X**	**X**	**X**
Test of exogeneity of log profit (Robust F)	[0.00]	[0.01]	[0.00]	[0.36]
F-statistic for first stage excluded instruments	18.67	18.67	18.67	-
Test for weak instruments:Craig-Donald Wald F statistics **[Stock-Yogo Critical value at 15% maximal IV size]**	18.69 [8.96]	18.69 [8.96]	18.69 [8.96]	-
R square	-	-	-	0.16
Number of observations	595	595	595	595

Notes: Values in parenthesis are p-values. *, ** and *** indicate significant differences at the 10%, 5% and 1% levels, respectively. The test for weak instruments is implemented using the Cragg-Donald F-statistic. The confidence intervals in brackets represent the identification-robust 95% confidence intervals for linear IV, calculated using the 'twostepweakiv' package by Sun (2018).

Table 15: Mediation model for low-cost feed

	Panel A: 2SLS/OLS			
	Outcomes			
	Log of household dietary diversity score	**Log of total daily per capita calorie intake**	**Log of daily per capita calorie intake from cereals**	**Log of daily per capita calorie intake from animals (OLS)**
Mediator				
Log of annual pastoral profit	0.339*** (0.007) [0.175, 0.676]	-0.808 (0.124) [-2.213, -0.137]	-1.237* (0.058) [-3.061, -0.530]	0.434** (0.015)
Policy				
Access to low-cost livestock feed	0.154*** (0.004)	0.302 (0.108)	0.384 (0.106)	0.808*** (0.000)
	Panel B: First Stage			
	Mediator			
	Log of annual pastoral profit			
Policy				
Access to low-cost livestock feed	0.236* (0.069)			
Instruments				
Livestock disease	0.613*** (0.000)			
Control variables	**X**	**X**	**X**	**X**
Test of exogeneity of log profit (Robust F)	[0.00]	[0.00]	[0.00]	[0.41]
F-statistic for first stage excluded instruments	15.90	15.90	15.90	-
Test for weak instruments:Craig-Donald Wald F statistics	17.89	17.89	17.89	-
[Stock-Yogo Critical value at 15% maximal IV size]	[8.96]	[8.96]	[8.96]	
R square	-	-	-	0.17
Number of observations	585	585	585	585

Notes: Values in parenthesis are p-values. *, ** and *** indicate significant differences at the 10%, 5% and 1% levels, respectively. The test for weak instruments is implemented using the Cragg-Donald F-statistic. The confidence intervals in brackets represent the identification-robust 95% confidence intervals for linear IV, calculated using the 'twostepweakiv' package by Sun (2018).