How Do Agro-Pastoral Policies Affect the Dietary Intake of Agro-Pastoralists? Evidence from Niger [1]

Abstract

Agricultural policies in poor rural developing countries typically aim at improving household nutrition by raising households' agricultural profit and presumably their dietary intake as a consequence. However, it is not clear how much of the impact of these policies goes through profit in practice. If the proportion is large, this would confirm the policy orientation and direct the attention of policy makers toward the different financial incentives. Even full activity substitution may occur, which may transform households' lifestyles and access to nutrient sources and thereby affect their nutrition. If, in contrast, the policy impact does not go through profit, then the policy perspective should be adjusted, and a thorough examination and monitoring of its other channels of influence should be undertaken.

Using statistical mediation analysis, we investigate the mechanisms underlying the effect of agricultural policies directed toward pastoralist households on their dietary intake in terms of these direct and indirect (through profit) effects. Based on an agro-pastoral survey conducted in Niger in 2016, the effects of livestock extension services associated with better access to markets are found to be channeled mostly through pastoral profits, while this is not the case for private veterinary services and low-cost livestock feed programs. Livestock extension services may foster agro-pastoral households specialization in cattle and sheep raising, which incentivizes them to switch toward a frequent pastoral transhumance, and limits their access to cereals, a valuable source of calories. As a result, livestock extension services are found to damage their total calorie intake.

Keywords: Agropastoral Policies, Mediation Analysis, Agricultural Households Models, Niger

JEL Code: Q12, I18, D13

I. Introduction

Agricultural policies in poor developing countries are often motivated by the improvement of the nutritional status of rural populations. These policies are generally designed with the aim to increase the production profit of farm households or pastoral households, in the hope that higher income will result in better dietary intake. Improving dietary intake can boost nutrition status, for example, as measured by anthropometric variables (e.g., in Puentes et al., 2016). Accordingly, household agricultural profit remains the indicator most widely used to monitor the success of agricultural policies. However, it is unclear whether the impact of these policies actually goes through the agricultural household profit and in which proportion or whether it goes through other, often overlooked, channels.

Learning that a policy effect does prominently operate though the agricultural profit would first corroborate that the design of the policy mechanism, targeting profit, is sound. This is far from obvious in contexts of missing and imperfect markets, in which the separation of production and consumption decisions has often been rejected (Benjamin, 1992, Muller, 2014) and where household choices may therefore involve more complex and extended transformations. Moreover, it would direct the attention of policy makers toward the financial incentives that producers follow in developing and selecting their activities. In particular, changes in activity specialization or sector 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 dwelling and consumption habits, and in the constraints they face for gathering the ingredients of their meals. As we will show below, this may imply, in Niger, that some policies that foster pastoralist incomes may have harmful consequences for the calorie intake of some beneficiary households.

Instead, finding that the policy operates through channels other than agricultural profit or other production level measures would push policy makers to adjust their perspective on how the policy works. Policy makers would be pushed to turn their focus to other pathways less directly connected to market and production processes. For example, local community networks, diversion of assistance,

informal exchanges and gifts, and power games within and between households may be comprised in the repercussions of the policy. These policies may also be the occasion of valuable information transmission among households and generate externalities through the creation of new network links. In this case, all these alternative policy channels may require more attention from policy makers than the narrow production channels.

Our goal is to investigate these issues. To do so, using statistical mediation analysis, we will assess the relative importance of direct and indirect (through profit) effects of some pastoral policies in the case of Niger. In particular, our results will highlight the interest of monitoring the financial incentives generated by policies for pastoral versus other activities. Furthermore, they will emphasize the importance of accounting for lifestyle switches in assessing agricultural policies, at least in this context. Finally, considering these elements will allow us to present an overlooked perverse effect of some agricultural policies: household nutrition may be damaged by changes in diets that accompany the triggered switches in activities and lifestyles, such as when sedentary agricultural households move to frequent pastoral transhumance, and as a consequence, lose access to valuable cereal sources of calories.

All these questions are likely to be relevant for many agricultural regions and poor developing countries. However, we will shed some light on them by investigating the case of agro-pastoral households in a Sahel country, for which they are particularly relevant. Indeed, the Sahel region is one of the poorest in the world. The Food and Agricultural Organization of the United Nations (FAO, 2016) estimates that an average of 20 million people suffer from malnutrition and food insecurity in the region each year, mainly during the lean season. In 2016, nearly 6 million children under five were acutely malnourished in the Sahel, which contributes to one-third of child mortality. Although van Wesenbeeck, Keyzes and Nubé (2009) find a lower prevalence of hunger and less inequality in mean calorie intake in Africa than does the FAO, undernutrition still appears to be frightfully severe in the Sahel.

For decades, Sahelian countries have tried, on their own or jointly, to provide solutions to this problem through agricultural policies. One of the key sectors on which these policies have focused is pastoralism, which is well fitted to the agro-ecological conditions and is the main source of income for many households in this region. In particular, the PRAPS regional project, financed by the World Bank in six Sahel countries, assists the development of pastoralism. Its main objective is to improve the income, productivity, sustainability, and resilience of pastoral livelihoods. We base our investigation on the (only usable) Niger survey of this project. Again, in this context, the policies that target pastoralist or agro-pastoralist households seek to improve their farm profit through an increase in their livestock output or a reduction of their production costs.

The linkages between agricultural and pastoral activities, diets and nutrition statuses may be complex. For subsistence or 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 generally 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 (The World Bank, 2007; Herforth and Jody, 2014). Moreover, with access to markets and extra income from output sales, they can purchase higher quality food.

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.[2] Here, we examine a specific link in these potential interactions, namely, how agricultural profit may impact dietary intake. However, one issue is that the health and nutrition status of producers may also directly affect their productivity and efficiency, as found by Croppenstedt and Muller (2000) in Ethiopia. Moreover, food aid programs sometimes simultaneously provide food aid and production-related assistance (as in Brück et al., 2018). This implies that endogeneity issues may arise when estimating an equation determining

---

[2] Muller, 2009; Carletto, Ruel, Winters, and Zezza, 2015; Dillon, McGee, and Oseni, 2015.

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 by using methods akin to those discussed in Heckman and Pinto (2015) and Vanderweele (2015). Mediation analysis has already been used to analyze the impact of promotion campaigns for staple food adoption on dietary intake (de Braw et al., 2018). Instead, we inspect household pastoral profit as a potential mediator in diverse policies aimed at raising pastoral profits. We apply this new approach to the case of Niger and three types of policies: (i) livestock extension services, (ii) veterinary services, and (iii) input subsidies. As mentioned before, in addition to their indirect effects through profit, these policies may have direct effects. For example, they may affect nutritional outcomes through the resale or transfer of the received goods and services to other households. Neglecting these potential mechanisms, as well as others, may bear consequences for household food consumption and dietary intake.

The rest of the paper is organized as follows. In Sections 2 and 3, we present the context of the study and the data. Section 4 discusses the empirical strategy, while Section 5 reports the estimation results. Finally, Section 6 concludes the paper.

II.   The Context

II.1. Livestock, poverty, and malnutrition in Niger

Niger is a large, landlocked African country with a population of 17 million in 2014. The country's economy is essentially based on agriculture in a broad sense. Forty percent of Niger's GDP is derived from the agricultural sector, while 11 percent stems from the livestock sector (Ministère de l'Elevage, 2016). Of Niger's total population, 87 percent are involved in the livestock sector as a primary or secondary activity, while, 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 of the 4,000 households interviewed raised livestock. Moreover, in rural areas in 2005, four out of five surveyed households held or kept, on average, 2.8 tropical livestock units (TLUs)[3] per household.

Most of the Nigerien households raising livestock are poor. Haan (2016) states that between 2008 and 2013, based on their income or expenditure levels, up to 30 percent of the pastoral and agro-pastoral populations were very poor, while 30 percent were poor, 20 percent were considered to be middle income and 20 percent were well-off. However, measured monetary income typically omits the asset value of livestock, which may lead to underestimating the wealth of these households. It also misses the role of livestock as a source of insurance and prestige.

Currently, the combined effects of climate change, drought, flooding and desertification, and demographic pressure have brought the pastoral economy into disarray. In the purely pastoral sector, the mean livestock ownership is only 1.9 TLUs per capita, and 0.6 TLU per capita in the agro-pastoral sector. According to Haan (2016), these levels are low when compared to "the minimum required to meet basic needs, avoid livestock inbreeding, and recover from drought, which is

---

[3] 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. See the International Food Research Institute and Harvest Choice : http://harvestchoice.org/data/an05_tlu for more details. The benchmark tropical livestock unit is commonly taken to be an animal of 250 kg liveweight (International Livestock Centre for Africa, 1988).

between 2.5 and 4 TLU per capita for pastoralist households and half of that for agro-pastoralist households". This is a matter of concern because below this level, households are confined to poverty even in good times. In contrast, households above this threshold may be able to not only regenerate herds after droughts but also use their animals to maintain the social networks on which they can rely during critical periods.

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 & Bauer, 2013). In 2010, 26.8 percent of agro-pastoralist households were most affected by food insecurity, with global acute malnutrition (GAM) among children under five years very severe in agro-pastoral and pastoral areas. In the Tilaberi region, GAM was up to 14.8 percent, which is near the WHO's maximum threshold of 15 percent (United State Agency for International Development, 2011). This calamity was largely a consequence of the 2009/2010 food crisis, which was characterized by harvest collapse, a very short rainfall period, and consecutive years of prolonged droughts.

II.2 Agricultural policies in Niger to alleviate poverty and food insecurity

In 2011, one year after the food crisis, the country put in place a long-term agricultural and food policy program, denoted "Initiative 3N: les Nigériens Nourissent les Nigériens" (Nigeriens Feed Nigeriens). The aim of this program is to end famine and malnutrition in the country by 2035. Precisely, in the livestock sector, the specific goals of this policy are (i) to increase fodder availability by creating livestock feed warehouses, livestock feed banks, mills, and municipal supply centers; (ii) to increase water availability by digging wells; (iii) to develop vaccination for animals; (iv) to enhance extension services targeted toward pastoral and agro-pastoral households; and (v) to give fodder, multi-nutrient block and fodder seeds to vulnerable pastoralist and agro-pastoralist households.

In this study, we analyze how these components of Initiative 3N affect the dietary intake of these households through their pastoral profit, or otherwise. In particular, we focus on the three main policies: livestock extension services, private veterinary services and low-cost livestock feed.

Livestock extension services

The livestock extension services enhanced by the Initiative 3N 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, also called "the peasant's house". The peasant's houses are held by government technical services, municipalities, farmers' associations or cooperatives. The livestock feed bank also seeks to i) bring livestock feed closer to the most remote households and ii) provide a security stock that can be mobilized during the hot dry season when livestock feed is scarce on the market and especially expensive. The second type of advice is typically provided at the beginning of the pastoral season every year by farmers' associations and by technical services of the Ministry of Livestock.

Private veterinary services

Private veterinary services are delivered either by a private veterinarian or by local private veterinary assistance. On the one hand, private veterinarians are generally based at the department level. They often hold a veterinary pharmaceutical stock with the mandate of carrying out free vaccination campaigns financed by the government. On the other hand, local private veterinary assistance is led by a private veterinarian who runs a network of approximately thirty assistants. An assistant is a private agent who can perform in ten to fifteen villages. These assistants may be community agents, such as villagers chosen by the community, and trained by the private veterinarian. Local private veterinary assistance provides households with various animal health services, such as vaccination, treatment of animal diseases, and advice. This service is part of the policy of liberalizing the veterinary profession, as promoted by the government.

Low-cost livestock feed (input subsidies)

Each year, the government assesses the country's fodder needs and purchases fodder to meet needs in deficit areas. The purchased stock is sent to the peasant's houses for sale at moderate prices. However, the purchased stock never covers more than fifty percent of the needs (Ministère de l'Elevage, 2015). Let us now turn to the data used for the estimations.

III. Data and Variables

III.1. Data

This paper uses data from a specialized survey collected by the Ministry of Livestock in Niger. This survey was conducted for two 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, which was conducted in October 2016[4]. The survey covered the seven regions of the country, and 1,350 pastoral and agro-pastoral households were sampled. First, 90 villages were selected proportionally to their size, as recorded from the national directory of localities. Then, within each selected village, 15 households were randomly drawn. In each village, households were a priori divided into three categories (small, medium and large producers) according to the size of their herds and in close collaboration with the villagers.

The surveyed households were asked about their socio-demographic characteristics, budget, food consumption, agro-pastoral production, livestock holdings, agro-pastoral sales and the prices they each face. The same survey provides information on different shocks that these households suffered (shocks related to animal fodder, animal diseases, and access to water) and on their strategies in response to these shocks. Finally, there is precise information on the access these households had to the three examined agricultural policies (input subsidies, veterinary services and livestock extension services).

---

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

Furthermore, we employ the global positioning system (GPS) of coordinates for matching each surveyed household with climatic data on local precipitation and temperature. For each household, we collect annual data on minimum, maximum and average temperatures in degrees Celsius at two meters of altitude and annual precipitation data measured in millimeters per day from the website for NASA's Prediction of Worldwide Energy Resource Project. The climatic data collected are averaged at the departmental level. This provides us with instrumental variables that will allow us to handle endogeneity problems in our regressions. The use of temperature data at the departmental level allows us to take into account the pastoral mobility of households in search of water and pasture for their animals.

In this study, we are constrained to focus on households that own sheep and cattle, which is therefore our population of reference. Indeed, first, only the information collected on this group of households is complete enough to be usable for econometric analyses. For example, these are the only households for whom we have data on livestock price costs and production levels. Another primary reason to focus on these pastoral and agro-pastoral households is that agro-pastoral policies should not directly affect households that have no pastoral activity. This leaves us with 600 household observations after cleaning the data and removing outliers[5]. In our final sample, the majority of households (almost 93 percent) are considered to be agro-pastoralist households, while only 7 percent are purely pastoralists. Pastoral households are defined as those that do not usually produce agricultural products and possess a significant number of animals (they are at least a medium herder). Moreover, their first and even second principal activities are livestock production and not agricultural production.

---

[5] In our sample, nearly 42 percent of households do not own cattle or sheep, they own goats, poultry, donkeys, or camels. When we exclude these households from our initial database, we are left with about 785 households. Then the extreme values (top 10% of the distribution) on calories consumed and pastoral profit were removed. However, note that some agropastoral policies could induce non-pastoral households to enter these activities. We cannot control this potential entry process with these data. On the other hand, we found no indications that such process are actually taking place in the academic and administrative literature, Niger's statistical sources, or during the interventions and focus groups that we conducted in Niger.

III.2. Construction of variables

In this subsection, we present the outcome and treatment variables. We define two distinct types of outcome variables: dietary intake indicators and household profit from livestock activities. The three treatment variables correspond to the considered agricultural policies. Each treatment is described by a dummy variable that takes a value of 1 when the household reported that it had access to the policy and 0 otherwise.

Dietary intake indicators

Two nutrition indicators are constructed: the household *dietary diversity score* and the household *calorie intake per capita per day*. The *dietary diversity score* records how many different food groups have been consumed by the household over a given reference period, which makes it a good proxy for diet quality. Following the FAO, 12 food groups are used to compute the *dietary diversity score* (Swindale & Bilinsky, 2006). Table 1 shows how the food products recorded as consumed by the households are categorized into these groups.

Table 1: 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, 0 otherwise. As we can see 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 for agro-pastoralists[6]. Finally, a *dietary diversity score* is defined for each surveyed household as the total unweighted number of food groups consumed by the household.

Calorie intake per capita per day

The *calorie intake per capita per day* for each household is computed by converting the recorded food quantity 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 coming from cereals (millet, sorghum, bread, maize and edible pasta) and from animal food products (meat, poultry, fish, fresh milk, curdled milk and cheese).

Profits from livestock activity

The last outcome variable is the household annual profit from livestock activity. After several attempts, we decided to consider only three outputs: cattle, sheep and milk production (fresh milk and curd), which correspond to the most accurately measured information. For cattle and sheep, we used the animals sold and slaughtered by the household as a measure of output because variations in stocks are unobserved. For milk, we used total household production. There are no data on stock variation for milk production between the two years.

All these production measures were valued at the market prices[7] faced by each household. The total of these production values amounts to the gross income of the households from pastoral activity.

For production costs, we were able to track four monetarily valued costs: costs related to the herd's health, livestock water consumption, feed consumption, and labor costs (for shepherds and market middlemen during the sale of animals). These costs are reported by each surveyed household for the whole herd. The (restricted) profit is obtained by subtracting the total observed costs from the

---

[6] 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. Although such approximate measurement of dietary intake is worrying, this is a common case with food consumption surveys. Econometrics methods partly deal with this by allocating these measurement errors to the error term in regressions in which the dependent variable is a measure of dietary intake.

[7] 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.

obtained gross income. All other unobserved costs and benefits must be neglected, as they were not observed. In the next subsection, we briefly discuss a few descriptive statistics.

III.3. Summary statistics

Household characteristics

Table 2a reports a few descriptive statistics for the variables used in this study. The average age of the household head in our sample is 45 years, and nearly 95 percent are male. The majority of the heads (94 percent) have no education, with only 4 percent having received primary education. We also note that the average size of households 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 seven regions of the country are grouped into two zones: the North and the South. The North is formed by the regions of Agadez, Diffa, Maradi and Zinder and the South by the regions of Tahoua, Dosso and Tillabery. Most of the households in our sample (60 percent) live in the South.

Table 2a: 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 profit from livestock production (Millions of CFA)	600	3.89	18.3	-1.63	0	0.21	1.15	257
Policies								
Access to livestock extension services (1 if yes and 0 otherwise)	600	0.19	0.39	0	-	-	-	1
Access to private veterinary services (1 if yes and 0 otherwise)	600	0.20	0.40	0	-	-	-	1
Access to 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.

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 belong to the category of small herders. Only 15 percent of the households surveyed are large herders. When considering all categories, the average number of animals per household is 10 for sheep and 7 for cattle.

As mentioned above, dietary intake is measured by two indicators: the calorie intake per capita per day and the dietary diversity score. In our sample, 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 calorie intake of less than 1,584 Kcal per person per day, while for 50 percent of the households, the intake is less than 2,775 Kcal per person per day. Large outliers seem to be related to ceremonies and food stock, although this cannot be fully ascertained in these data. 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 seems likely that calorie intake from animal products has not been fully recorded. In particular, omission errors may occur due to the large recall period for consumption, which is 3 months. Moreover, animal products are sometimes mixed with vegetable products when consumed and, in that case, may have been overlooked in meal description.

The extreme values observed in household calorie consumption data are not necessarily irrelevant outliers. Indeed, one simple method to detect outliers in univariate data is based on boxplots. However, by observing the distribution of these data, we can see that they are skewed and have a long tail, which makes the standard boxplot method ineffective, as Bruffaerts et al. (2014) have pointed out. For this type of data, these authors proposed the generalized boxplot method that deals with these data characteristics (see also Verardi and Vermendele, 2018). With the logarithmic transformation, the values that could have been considered outliers no longer seem to be so (see Appendix 1). This supports our choice to transform the data before estimating regressions. Additionally, as noted by Atkinson (1982), "in some cases, apparent outliers can be brought into agreement with the remainder of the data by use of a transformation".

Table 2a shows that the profit level varies substantially across households. On average, annual profit is 3.89 million CFA francs. Over the survey period, 25 percent of households had a zero profit, while half of households enjoyed a profit above 214,073 CFA francs. The households with zero profit correspond to those

with very limited pastoral activity. The greatest observed profit loss is nearly 1.6 million CFA francs. This may be partly due to measurement errors and partly to the fact that annual profit is an imperfect measure of economic activity for livestock raising, the production horizon of which may extend to many years.

Our outcome variables, the two household dietary intake indicators and the profit variable, are each transformed into logarithmic form for the econometric analysis. When transforming the annual livestock profit into logs, we add a constant amount to the profit level to accommodate negative values. The transformed profits are therefore log (profit + constant), where the constant is equal to the minimum observed value of profit 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 report having access to livestock extension services and low-cost livestock feed, respectively.

As we can see from Table 2b below, the outcomes of households that have access to a policy generally differ from those that do not. The households that have access to livestock extension services have a 42 percent lower calorie intake than those that do not. However, their dietary diversity score is 14 percent higher than that of nontreated households. They also consume more animal food products and less cereals than households that do not have access to livestock extension services. Households with access to low-cost livestock feed or private veterinary services have a higher dietary diversity score and consume more animal food products than cereal products, different from households that do not have access to these policies. Regarding the annual profit from livestock production, we note that for the three considered policies, households that have access to each of these policies are better off than those that do not. These data are therefore suggestive for the analysis that we want to conduct. We describe our empirical strategy in the next section.

Table 2b: Summary statistics

	Policies								
	Livestock extension services			*Low-cost livestock feed*			*Private veterinary services*		
	No Access	Access	Diff	No Access	Access	Diff	No Access	Access	Diff
Outcomes (mean values)									
Log of total calorie intake per capita per day	7.81 (.05)	7.38 (.14)	.42*** (.14)	7.71 (.06)	7.77 (.12)	-.05 (.15)	7.77 (.06)	7.54 (.10)	.23* (.14)
Log of calorie intake per capita per day from cereals food product	7.56 (.06)	7.07 (.15)	.50*** (.14)	7.46 (.06)	7.52 (.12)	-.06 (.16)	7.53 (.06)	7.22 (.10)	.30** (.14)
Log of calorie intake per capita per day from animal food product	3.73 (.08)	3.88 (.19)	-.15 (.19)	3.69 (.08)	4.15 (.18)	-.45** (.21)	3.71 (.08)	3.95 (.17)	-.24 (.19)
Log of household dietary diversity score	1.58 (.02)	1.72 (.02)	-.14*** (.04)	1.57 (.02)	1.80 (.02)	-.23*** (.05)	1.57 (.02)	1.76 (.03)	-.19*** (.04)
Log of annual profit from livestock production	14.69 (.05)	14.96 (.09)	-.26*** (.10)	14.71 (.04)	14.94 (.11)	-.23** (.12)	14.73 (.05)	14.83 (.08)	-.10 (.10)

Notes: Values in parentheses are standard errors. *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively. Column Diff shows the mean difference, for the outcome variable, between the group of households that do not have access to the policy and the group that does have access to it.

IV.   Empirical Strategy

As mentioned above, our aim is to empirically investigate the mechanisms behind the impact of agricultural policies on household dietary intake. Specifically, we want to assess the role played by pastoral profits in this process. In contrast, mainstream policy evaluation methods focus primarily on estimating the average treatment effect rather than investigating the underlying channels that drive this effect.

In the statistical literature, analyzing the channel through which a policy effect occurs, with a specific interest in the role of a particular variable, is referred to as mediation analysis[8]. A particular variable of interest is the potential *mediator of effects,* which in our case is the profit from livestock activity. Mediators in agricultural production technology have been identified by Heckman and Pinto (2015) using treatment effect estimators. Our approach mixing ATE estimators and regression estimators is somewhat akin to their econometric setting (p. 4, or eq. 19 p. 16). Consistent with this setting, the identification relies on ignorability conditions, controls, and instrument exclusion conditions.

Mediation analysis has been especially used in medicine, psychology and political science, in both experimental and observational studies. There is growing interest

---

[8] Imai, Keele, Tingley, & Yamamoto (2011); Vanderweele (2015).

in extending the use of this method in economics[9]. Our empirical strategy is a form of mediation analysis, in which we investigate the extent to which the impact of agricultural policies on pastoralist household dietary intake in Niger is mediated by the profit from livestock activities.
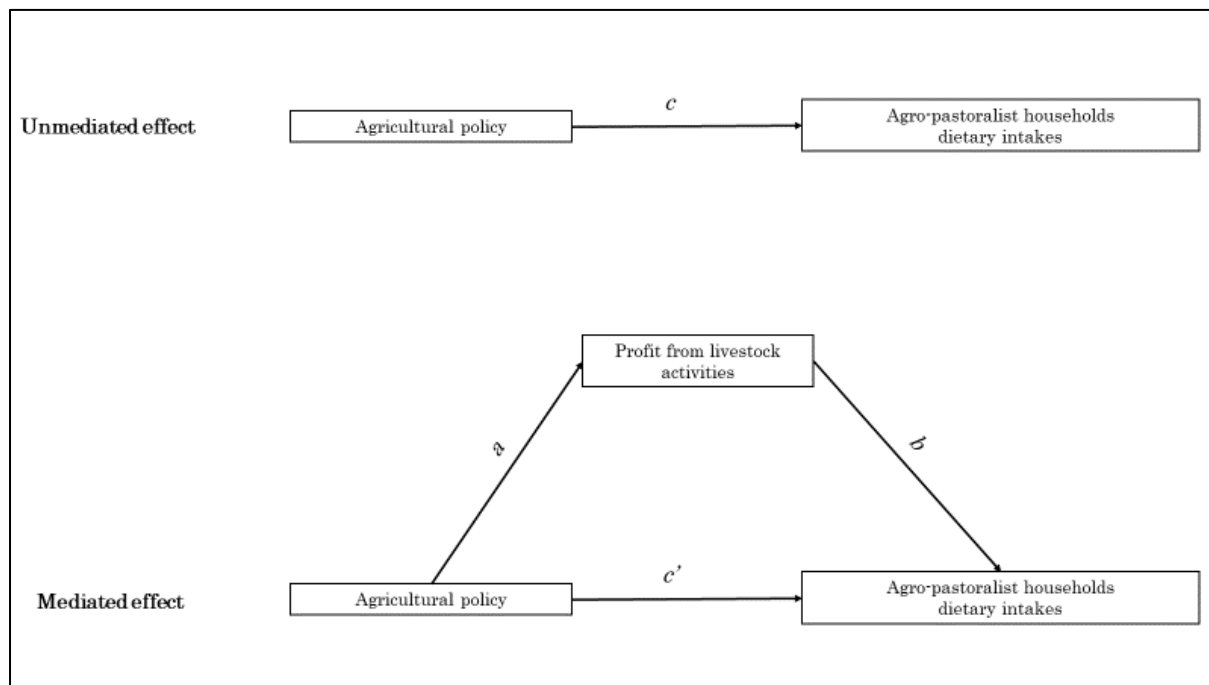

Figure 1: An illustration of our empirical strategy

This strategy can be specified in terms of the four links (a, b, c and c') displayed in Figure 1. The first link represents the total effect (c in Figure 1) of the considered agricultural policy on the dietary intake indicators for pastoralist households. Link a represents the effect of the policy on profit, which is the mediator, while link b represents the effect of profits on household dietary intake. The second two links are used to assess the indirect effect of the policy on household dietary intake, that is, the effect that is mediated through profits. Finally, the last link c' represents the direct effect of the policy on household dietary intake, that is, the effect that operates through channels other than the annual profit.

To analyze this mediation, we use a combination of cross-sectional and retrospective observational data, which were collected in 2016, five years after the

---

[9]Heckman et al. (2013); Kosec, Ghebru, Holtemeyer, Mueller and Schmidt (2018); de Brauw et al. (2018)

beginning of the implementation of Initiative 3N. However, we do not have any information on these households before 2011.

IV.1 Estimating the unmediated effect (c) of policies

In this first step, we estimate a model of selection on observables for the potential outcomes with and without treatment (i.e., with and without policy access).

In Niger, households may choose to have access to different agricultural policies. In that case, they select themselves into the treatment. In this context, our identification strategy of the treatment effect relies on assuming conditional mean independence between the treatment and the outcomes. For the studied question of policy analysis, the issue of identification always arises. Given the limited data at our disposal, attempting to address this issue by relying on an approximate hypothesis of selection based on observables seems to be better than neglecting selection and endogeneity issues.

We evaluate the effects of the three policies separately because each policy was originally intended to resolve a specific problem. Therefore, depending on its needs, a household can decide to use different policies at different points in time, separately, or not at all. For example, a household can decide to use private veterinary services during the dry and wet season, a season favorable to the development of livestock diseases. However, in the dry and hot season[10], the household may instead decide to use the low-cost livestock feed program because of the scarcity of pastureland during this season. Thus, before deciding to use the low-cost livestock feed program, the effect of private veterinary services may have already been observed by the household in the previous season. Then, the household's decision to use low-cost livestock feed is clearly not simultaneous with its previous decision to use private veterinary services. In that case, jointly evaluating the simultaneous effects of the three policies does not seem to be appropriate. Moreover, the survey does not provide any information on the precise

---

[10] 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.

time of the year when each household accessed and used each policy. Therefore, we prefer to assess the impact of each considered policy separately.
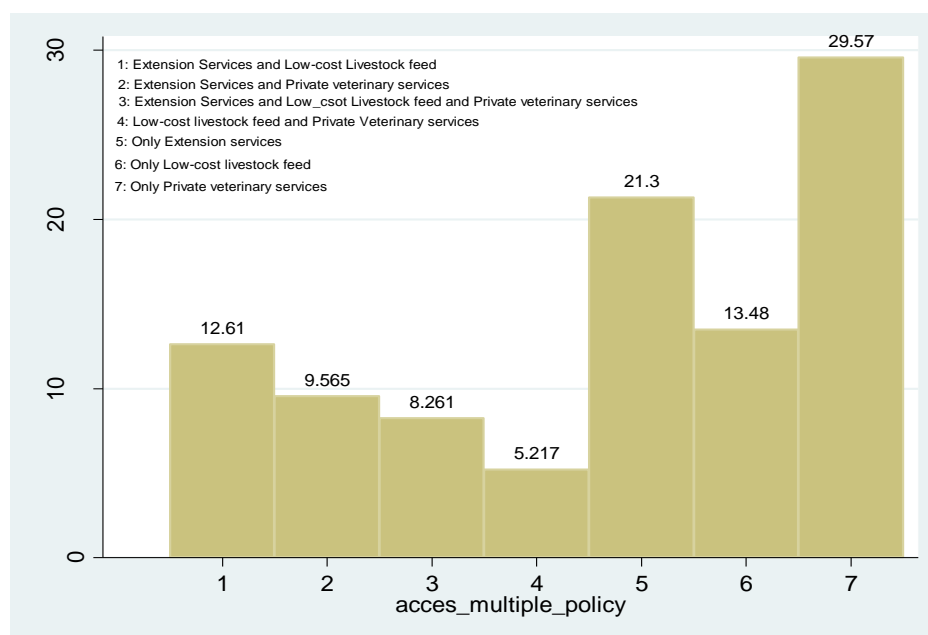

1: Extension Services and Low-cost Livestock feed
2: Extension Services and Private veterinary services
3: Extension Services and Low_csot Livestock feed and Private veterinary services
4: Low-cost livestock feed and Private Veterinary services
5: Only Extension services
6: Only Low-cost livestock feed
7: Only Private veterinary services

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

In addition, over the year, households may have accessed all the policies, although not simultaneously. Indeed, as one can see from Figure 2, among the households that have access to at least one of the three policies (213 households), only 8.26 percent have access to all three policies during the whole year. Additionally, the majority of these households have access only to private veterinary services (29.57 percent), which is consistent with livestock disease being a major concern for them. The questionnaire includes information on the households' assessment of the services they have accessed. This information is censored because it is only available for households that have had access to the services. The assessment is approached from three angles: physical accessibility to these services, cost and quality. Each household was asked to indicate, for a given service, whether it was easily accessible, whether it was cheaper than what is available on the market and whether it was of good quality.

As shown in Table 3, households' assessment depends on where they live. Indeed, households living in the South of the country seem to have easier physical access to livestock extension services than those living in the North. In fact, the

proportion of households that had access to this policy and that considered the policy easily accessible is significantly higher for households living in the South than for those in the North. However, the opposite situation is observed for private veterinary service, where access seems to be easier for households living in the North than for those in the South. On the other hand, for these two policies, there is no significant difference between North and South in terms of households' evaluation of cost. It is only the assessment of the cost of the low-cost livestock feed service that is significantly different; namely, it is considered to be cheaper in the South than in the North.

Table 3: Households' assessment of the policies

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

Notes: Values in brackets are the number of households that used the policy. Values in parentheses are standard errors. *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Finally, the households' assessment of quality is more positive in the South than in the North for livestock extension services, while it is more positive in the North for private veterinarian services. Assuming, for a moment, that these assessments can be generalized to households that have not had access to these policies, it could be said that these assessments (physical accessibility and cost of service) can influence households' decisions to use these services, just as they (quality of service) can have an impact on the outcome being measured. It would therefore be

important to take this information into account in our estimates. 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 will allow us to incorporate part of this information.

In the literature, various methods have been proposed to construct a counterfactual based on nonexperimental observations. We use the inverse probability weighted regression adjustment (IPWRA) method, discussed in Wooldridge (2010), which combines regression adjustment (RA) and inverse probability weighting (IPW). One model is specified for the outcome

$$Y_i = f\left(X_i, \beta\right) + \varepsilon_i,$$

(1)

and another for the treatment

$$\Pr\left(T_i = 1\right) = g(X_i, \lambda),$$

(2)

for households i = 1...N, where N is the total number of households in our sample. In equations (1) and (2), X_i is a set of covariates that influence both the outcome, Y, and the dummy variable for treatment, T. β and λ are parameter vectors to estimate, while ε_i is an error term. The function f can be specified as a linear function when the outcome is continuous, as in our case. As is also typical, we specify the function g to be a probit function. One advantage of the IPWRA method is that, under the usual ignorability assumption, one can obtain a consistent estimator of the effect of the treatment even if one of the two models is miss-specified (Wooldridge, 2007). In RA, a linear regression can be specified to generate a predicted outcome, while no restriction is imposed about the treatment. Alternatively, in IPW, a probit regression can be used to predict the treatment status, while no formal model is assumed for the outcome.

We choose covariates that vary little over time to account for the fact that the data were collected five years after the beginning of the implementation of Initiative 3N. These stable covariates are in a sense surrogates for missing pretreatment covariates not affected by the treatment. Indeed, we lack baseline information on households before the policy implementation.

The observed characteristics that are assumed to affect the outcomes and household participation are the sex, highest reached education level and age of the household head, the region of residence (North or South) in line with the argument developed above, the proportion of children below 3 years of age, the proportion of children between 4 and 10 years of age, and the proportions of youths and young adults. These characteristics are likely to affect household food demand and diet composition. In particular, household composition may condition the type of food products that are consumed and shared within the household. For example, households with children may consume more milk. Additionally, some household characteristics, such as the sex, age or level of education of the household head, can affect a household's access to a given policy. Indeed, households with a high level of education can more easily obtain information about a policy, such as its start date and where it is implemented. Furthermore, some policies, such as livestock extension services, may require minimal education to be able to implement the advice they provide. Finally, although this is not well recorded, the Initiative 3N may target some specific households on the basis of these sociodemographic characteristics.

We also include the household's ethnic group and its livestock holding category in the treatment models since these characteristics may drive a household's willingness to access a policy or be considered by public officials when targeting interventions. This may help us control for potential correlations between nutritional statuses and pro-poor policies. Recall that the holding categories correspond to a period prior to the survey and policy. However, we prefer not to use the livestock holding category as a covariate because this stratification may be too endogenous, notably when we will attempt to explain pastoral profit.

With the IPWRA method, the treatment effect is obtained by first estimating the parameters of the treatment model to generate the predicted probability of being treated for each individual, $g(X_i, \hat{\lambda})$, where $\hat{\lambda}$ is the estimate of λ. The obtained inverse probabilities for each observed household are used as weights in the regressions of the outcome models specific to each treatment (0 and 1).

Then, to estimate the parameters of the outcome models, the IPW least-squares estimator is calculated separately for each treatment:

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

and
$$\min_{\beta_1} \sum_i^N \frac{\left[Y_i - f(X_i, \beta_1)\right]^2}{g(X_i, \hat{\lambda})} \qquad \text{if} \quad T_i = 1 \; . \tag{4}$$

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

$$ATE = \frac{1}{N} \sum_i^N [f(X_i, \hat{\beta}_1) - f(X_i, \hat{\beta}_0)] \; , \tag{5}$$

where $\hat{\beta}_1$ and $\hat{\beta}_0$ are the estimated parameters.

This procedure is also used to estimate the impact of the considered agricultural policies on the presumed mediator, i.e., the annual profit from livestock activities, by simply substituting it as the outcome variable.

IV.2 The effect of pastoral profit

In this subsection, which corresponds to link b in Figure 1, we discuss the impact of the mediator on household dietary intake. We use a regression setting to estimate the mean effect while including control variables (X_i in the model below) that are the same as in the previous subsection.

However, as mentioned above, there might be feedback influences between household production strategies and nutritional status or other types of confounders. To control for this, we run a 2SLS regression to estimate the effect of annual profit on dietary intake. The three instruments for profit are, first, a dummy variable that characterizes the overall quality of the pastoral season as experienced by the household, second, the average annual temperature at the departmental level and third, its squared value. The first instrument reflects the

way in which the household experienced the previous pastoral season in terms of water and grazing availability and livestock disease. It takes the value 1 if the household assesses the context of the previous pastoral season as favorable and 0 otherwise. With regard to the two temperature-based instruments, heat stress has been found to affect livestock health through oxidative stress, metabolic disruptions, and reduced immunity to infections (Laceteva, 2019).

Formally, this amounts to jointly estimating the following two equations for each policy j:

$$\text{Log(Profit)}_i = \alpha_0 + T_{ij}\,\alpha_1 + Z'_i\,\alpha_2 + X'_i\,\alpha_3 + \omega_i$$

$$Y_i = \beta_0 + \text{Log(Profit)}_i\,\beta_1 + T_{ij}\,\beta_2 + X'_i\,\beta_3 + \varepsilon_i \tag{6}$$

β and α are vectors of parameters to be estimated, while ω_i and ε_i are the error terms of the second and first models, respectively. T_{ij} represents the jth policy's treatment dummy for the ith household, while Z_i denotes the three instruments for this household. While not indicated in the notations to save space, the parameters and error terms vary with the considered policy.

System 6 allows us to estimate the impact of the mediator on household dietary intake while controlling for household access to a policy. The joint presence of the profit and policy variables in the outcome equation corresponds to the partial contributions of the direct and indirect effects to a change in outcome. The other controls are similar to those used for the ATE estimates for the policies.

The three instruments are found to be significantly linearly correlated with the logarithm of household pastoral profit (correlation coefficients of 0.18 for quality of pastoral season, -0.15 for the maximum local temperature in level and 0.15 for the maximum local temperature squared). However, they must also be uncorrelated with the error terms in the calorie intake and the dietary diversity score equations. Under this exclusion restriction, the instruments influence the outcome only through their linear correlations with the logarithm of pastoral profit.

The exclusion restriction for the quality of the pastoral season is justified by the fact that it is typically unexpected by households. A very bad pastoral season is

characterized by a lack of water and pastureland and several spells of livestock disease outbreaks, which reduce herd fertility and milk production and negatively affect household pastoral profits. It seems reasonable to assume that, given all the controls, the quality of the pastoral season has no direct impact on diets or that this impact can be neglected.

Regarding the other two instruments, i.e., the local maximum temperature and its squared value, the exclusion restriction is made plausible by climatic shocks being beyond the control of households and unanticipated. Then, one does not expect diet habits, given all controls, to be significantly affected by temperature. The frequency and severity of hydrological and agricultural droughts increase as the temperature rises (Vincente-Serrano et al, 2014; Amrit et al, 2018). Thus, high temperature reduces the availability of pastureland and water for animals, which in turn negatively impacts milk production and animal weight and reduces the market value of animals.

Although exclusion restrictions are ultimately untestable, the observed correlations in the data are encouraging (not shown). First, the absolute value of the correlation coefficients of each instrument with each outcome is found to be approximately two times 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 profit. Second, under exogeneity of profit, the semipartial correlations would indicate a linear correlation of the instrument with the relevant error term. Although this is no longer a consistent criterion for selecting instruments when the profit is endogenous, it is reassuring to find that the semipartial correlations of temperature in level and its squared value are not significantly different from zero for the log of total calories or the log of calories from animal food products.

A last point that remains to be discussed further is the presence of the treatment dummy in the second equation in (6). This specification corresponds to our motivation of investigating mediation effects, and in particular indirect effects, by estimating how the treatment affects the outcome in the presence of a control by the profit variable in the same equation. In that case, consistent with the usual

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. This is possible here because the controls that were introduced for justifying ignorability in the average treatment effect estimation are also introduced in the two stages of the 2SLS. They can be seen here as proxying the relevant control function, as advocated by Wooldridge (2010). Indeed, in the typical control function approach for linear models, a residual $(I-(Z'Z)^{-1}Z')T$ is added to the equation to estimate, with Z denoting the controls and T denoting the potentially endogenous treatment. That is, the control function is a linear combination of a function of the normalized Z. In our approach, to simplify and make the procedure more comprehensible, we omit the normalization by $(Z'Z)^{-1}$ and directly introduce the Z as controls in the two estimation stages as needed.

IV.3 Estimating the indirect and direct effects

As mentioned above, the indirect effect is the effect that passes through the pastoral profit, while the direct effect (represented by link *c'* in Figure 1) is the effect that operates through channels other than pastoral profit. The sum of these two effects forms the total effect (represented by 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, using the ATE formula in (5), while the second effect *b* is obtained from the estimates of System 6 for parameter β_1. The direct effect *(c')* is therefore measured as the effect of the policies on the outcome when controlling for the effect of the mediator. It is measured by the parameter β_2 in the second equation in System 6. The identification of this parameter partly relies on the controls for household characteristics X_i, which make the assumed conditional independence between the treatment and outcomes more plausible.

The confidence intervals of the estimated indirect effect are computed with Monte Carlo simulations, as proposed by MacKinnon, Lockwood, and Williams (2004)[11]. We now turn to the estimation and test results.

V. Results

V.1. The total effects of the policies on dietary intake

The estimates of the unmediated, or total, effect of each of the three policies on nutrition intake are reported in Table 4. The hypothesis that the distribution of covariates is the same for the two treatment statuses is not rejected for any of the three policies. This reassures us that the IPWRA method has made it possible to construct two comparable groups on the basis of the covariates used in the estimates (see Appendix 3 for more details).

For the dietary diversity score, the average treatment effect of each of the three policies is positive and significant. Households with access to livestock extension services see their dietary diversity score increase by 14.3 percent relative to those that did not. Moreover, having access to private veterinary services increases a household's dietary diversity score by an almost identical extent of 14.5 percent. Finally, the total average effect of deliveries of low-cost livestock feed raises the dietary diversity by 21.7 percent.

With regard to calorie intake per capita per day, only livestock extension services have a significant impact. This impact decreases calorie intake per capita per day by 28 percent for households that have access to livestock extension services. The other two policies do not have any significant effects on total calorie intake. The effects of each policy are very similar when considering calorie intake from cereals. This suggests that the surprising negative impacts of livestock extension services on total calorie intake could be explained by a decline in the consumption of cereal foods.

---

[11] Starting with two estimates for the effects a and b and their standard errors, two simulated random normal variables a and b are generated to compute a distribution of $a*b$ values. With these values, confidence intervals and p-values can be estimated by their simulated analogs.

Table 4: Total effect of the selected policies on household dietary intake

	Log of household dietary diversity score	Log of total calorie intake per day and per capita	Log of calorie intake per day and per capita from cereals	Log of calorie intake per day and per capita from animal food products
	ATE	ATE	ATE	ATE
Livestock extension services				
Access to livestock extension services	0.143*** (0.03)	-0.281** (0.13)	-0.327*** (0.14)	0.261 (0.19)
Testing covariates balance: (Chi-square test)	*[0.80]*	*[0.80]*	*[0.80]*	*[0.75]*
Veterinary services				
Access to private veterinary services	0.145*** (0.04)	-0.194 (0.15)	-0.250 (0.16)	0.066 (0.21)
Testing covariates balance (Chi-square test)	*[0.38]*	*[0.38]*	*[0.38]*	*[0.47]*
Input subsidies				
Access to low-cost livestock feed	0.217*** (0.03)	0.099 (0.11)	0.081 (0.12)	0.379* (0.22)
Testing covariates balance: (Chi-square test)	*[0.93]*	*[0.93]*	*[0.93]*	*[0.96]*
Number of Observations	*596*	*596*	*596*	*511*

Notes: ATE: Average treatment effect. Values in brackets are p-values, and values in parentheses are robust standard errors. *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

However, opposite policy effects are observed for the calorie intake from animal food products. For both livestock extension services and low-cost livestock feed programs, the results show positive policy effects, although only the effect of the latter program is significant at the 10 percent level. Nevertheless, a positive and small nonsignificant impact is observed for private veterinary services. The positive effects, even if not significant, of livestock extension services and low-cost livestock programs are consistent with their presumed beneficial contribution to the dietary diversity score. Increasing the dietary diversity for households with diets mainly composed of cereals generally amounts to augmenting their consumption of animal food products. Nevertheless, the negative impact of livestock extension services on total calorie intake raises the question of its origin. Mediation analysis will shed further light on this.

Three hypotheses could explain this intriguing result. The first is the presence of a perverse effect of the examined policy, which may foster household specialization in pastoral activities at the expense of agricultural production. The second hypothesis is that the policy changed the food habits of agro-pastoralist households, which may have substituted additional consumption of animal food products for cereal food products. The third hypothesis is that of measurement

errors in calorie intake data. Examining these hypotheses, especially the first one, is the purpose of the next sections.

V.2. The effects of the policies on profit and production levels

Table 5 reports the estimated average treatment effects of the considered policies on household pastoral profit and cereal and milk production levels, all in logarithm.

Table 5: Effects of the policies on household profit and production levels

	Log of annual profit from livestock activity	Log of annual quantity of milk production	Log of annual quantity of agricultural production
	ATE	ATE	ATE
Livestock extension services			
Access to livestock extension services	0.231** (0.10)	0.569*** (0.20)	.155 (.16)
Testing covariates balance (Chi-square test)	[0.81]	[0.41]	[0.79]
Veterinary services			
Access to private veterinary services	0.082 (0.09)	0.296 (0.21)	0.445** (0.20)
Testing covariates balance (Chi-square test)	[0.33]	[0.60]	[0.63]
Input subsidies			
Access to low-cost livestock feed	0.168 (0.11)	0.144 (0.21)	-0.167 (0.18)
Testing covariates balance(Chi-square test)	[0.91]	[0.96]	[0.96]
Number of Observations	*595*	*326*	*482*

Notes: We consider only the three mains agricultural products: millet, sorghum and cowpea. ATE: Average treatment effect. Values in brackets are p-values, and values in parentheses are robust standard errors. *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

None of the three policies, except private veterinary services, have a significant impact on the production levels of the three mains agricultural (millet, sorghum and cowpea)[12]. Only livestock extension services have a significant and positive effect on the annual profits of households from livestock activity. Access to this policy increases a household's annual pastoral profit by 23 percent, on average. The effects of the two other policies on profits are positive but not significant. Additionally, these two policies do not have any significant effects on milk production.

In that sense, among the considered policies, only livestock extension services seem to have achieved the policy objective of enhancing pastoral profit, especially because they are the only ones with a positive and significant impact on milk production. In contrast, private veterinary services and low-cost livestock feed

---

[12] Of the surveyed households, 85 percent produce at least one of the three agricultural products.

programs have failed to reach this objective. It is therefore interesting to learn whether the positive effect of livestock extension services on household profits is transmitted to dietary intake.

The non-significant effect of veterinary services on household pastoral profit could be explained by households using this policy to limit the damage that diseases can cause to their herds. They do not seem to be taking a preventive approach when they decide to use this service but rather aim to care for sick animals. Therefore, when massive disease outbreaks occur in the considered year, the effects of this policy do not emerge. Moreover, when they face these negative shocks frequently and repeatedly, pastoral and agro-pastoral households may convert to agriculture to increase their capacity to meet their food needs in these difficult times. Indeed, there are reports about Tuareg herders in Niger switching to agriculture after experiencing livestock losses due to drought and disease (Le Point, 2019). This could partly explain the positive and significant effect of veterinary services on households' production of the main cereals.

Livestock extension services, the only policy that significantly and positively affects pastoral profit and milk production, also have a negative effect on calorie intake from cereals and a positive effect on calorie intake from animal products, as shown above in Table 4. Therefore, production and consumption substitution between cereal products and animal food products may have taken place after this policy, which would contribute to explaining these effects.

V.3. The effects of profits on dietary intake

As mentioned above, the effects of pastoral profit on dietary intake are estimated by running linear 2SLS regressions, in which the dietary intake measures are the dependent variables, and the annual profit is an independent 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 are presented in Tables 6a to 6c for the three policies.

With regard to livestock extension services (Table 6a), the exogeneity hypothesis of the logarithm of profit is rejected at the five percent level and below for all the considered dietary outcomes, except for the logarithm of calories from animal

products. This leads us to estimate the model using 2SLS with the three instrumental variables for dietary diversity score, total calories intake and calories intake from cereals, and OLS for calorie intake from animal products.

The results of overidentification tests indicate that the three instruments are valid at the five percent significance level. This is also the case for the two other mediation models (Tables 6b and 6c), which support the use of instrumental variable regressions. However, the results of the test of weak instruments of Olea Montiel and Pflueger (2013) suggest that our instruments may be weak. This leads us to implement the two-step weak IV methodology developed by Sun (2018), based on Andrews (2018), to compute identification-robust confidence sets.

The results of the first-stage estimation, reported in Panel B, show that households reporting a favorable pastoral season have a higher observed annual profit. For these households, the availability of good pastureland and water for their herds promoted production and profit. The coefficients of the two temperature instruments are also highly significant.

As explained above, to assess the direct effect of each policy, one must incorporate the treatment variable in the second stage of the 2SLS regression. This entails the additional incorporation of the treatment variable in the first stage, according to the correct formula for the 2SLS estimator. Using the controls in the 2SLS estimation makes not only the conditional independence of the treatment and the outcome but also the conditional independence of the instruments and the outcome more plausible.

The first-stage estimates indicate that the coefficient of livestock extension services on profits is significant in the instrumental equation for profits. This effect is similar to the one obtained in the previous section when estimating the effect of livestock extension services on profits with IPWRA (+22 percent with the 2SLS model and +23 percent with IPWRA), which is reassuring. In the two other mediation models, the estimated effect of the policy on profits obtained from IPWRA and the one obtained from 2SLS are also similar.

Table 6a: Mediation model for livestock extension services

	Panel A: 2SLS/OLS			
	Outcomes			
	Log of household dietary diversity score	**Log of total calorie intake per day and per capita**	**Log of calorie intake per day and per capita from cereals**	**Log of calorie intake per day and per capita from animal products (OLS)**
Mediator				
Log of annual profit from livestock activity	0.426*** (.120) [0.279, 0.821]	-0.712** (.236) [-1.562, 0.368]	-0.940*** (.267) [-1.995, 0.605]	0.412*** (.111)
Policy				
Access to livestock extension services	0.03 (.057)	-0.085 (.183)	-0.08 (.202)	0.141 (.206)
	Panel B: First Stage			
	Mediator			
	Log of annual profit	**Log of annual profit**	**Log of annual profit**	**Log of annual profit**
Policy				
Access to livestock extension services	0.22** (.106)			
Instruments				
Pastoral season (1 if good)	0.303*** (.103)			-
Annual maximal temperature in level	-21.635*** (6.471)			-
Annual maximal temperature squared	0.306*** (.09)			-
Control variables	X	X	X	X
Test of exogeneity of log profit (Robust F):	[0.00]	[0.00]	[0.00]	[0.95]
Test of overidentifying restriction (Chi square test)	[0.14]	[0.14]	[0.12]	-
F-Statistics for first-stage statistics for excluded instruments	8.61	8.61	8.61	-
Robust test for weak instruments: *Effective F statistic, MP test* *[Critical value at level = 10 level]*	13.17 [14.45]	13.17 [14.45]	13.17 [14.45]	-
R Square	-	-	-	0.12
Number of observations	595	595	595	516

Notes: Values in brackets are critical p-values, and values in parentheses are robust standard errors. *, ** and *** indicate significant differences at the 10%, 5% and 1% levels, respectively. The robust test for weak instruments is proposed by Olea Montiel & Pflueger (2013) and computed using a Stata package made available by Pflueger and Wang (2015). MP: Olea Montiel and Pflueger. The confidence interval in brackets is the identification-robust LC_2sls 95 percent confidence interval for linear IV. These confidence intervals are computed using the package twostepweakiv proposed by Sun (2018). The distortion cutoff level obtained from this test is 14%, 9% and 10% for the model of dietary diversity score, total calories intake and calories intake from cereals, respectively, which does not exclude the possibility of a weak instrument.

The effect of a one-percent increase in pastoral profit on a household's dietary diversity is statistically significant and almost the same for the three policy-specific mediation models, ranging from 0.42 to 0.43 percent. Clearly, there is a substantial positive impact of greater profit levels on dietary diversity. This impact is robust to the inclusion of any of the three policy dummies.

In contrast, a one-percent increase in profit diminishes total calorie intake per capita and per day by -0.75 to -0.71 percent, depending on the implemented policy. Moreover, the significant effect of profit differs in sign for the two distinguished calorie sources. Increasing a household's pastoral profit by 10 percent amounts to increasing its calorie intake from animal products by 4.1 percent and lowering its calorie intake from cereals by 9.5 percent, on average. These results are in line with policies altering the dietary habits of agro-pastoralist households toward a more diversified diet, which includes proportionally more calories from animal products. This transition may be driven by new incentives associated with an increase in pastoral profit and a greater specialization in pastoral activities. In Niger, specializing in livestock activities can be accompanied by a thorough metamorphosis in household lifestyle. With chronic shortages of pasture and water due to frequent drought, these households may turn to frequent pastoral transhumance in search of fresh pasture. This switch in livelihood can induce households to consume easy-to-find calories in the form of animal products, as opposed to cereals that may be difficult to come by. Nomadic households may also lose access to markets for specific food products, thereby restricting their food diversity. This difference in consumption pattern between nomadic and sedentary pastoralist or agro-pastoralist households was studied in Northern Kenya by Fratkin et al. (2006). According to these authors, a nomadic pastoral diet is characterized by calorie-poor and protein-rich food, which is consistent with our findings.

Moreover, whether for pastoral or agro-pastoral households, those who engaged in pastoral mobility[13] the year before the survey differ from the others in terms of their mean dietary intake (see Appendix 2). Those who engaged in pastoral mobility the year before the survey consume fewer calories, notably fewer from cereals, while they consume more calories from animal products 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

---

[13] 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 areas to wet areas with abundant grazing and water for animals.

specialization of households in pastoral activities may contribute to explaining the negative impact of some agro-pastoral policies on total calorie intake.

Law, Frases and Piracha (2020) provide additional evidence of the declining importance of cereals in household diet, this time for Indian households. In this case, while the shift away from traditional staples is attributed to a change in food preferences, it also corresponds, as in our case, to cereals being a substitute for rather than a complement to animal products in diet.

Among the three policies, the only one with a direct effect on the dietary diversity, which is significant at the five percent level, is that providing low-cost livestock feed. The direct effects of each of the three policies on calorie intake, either from cereals or animal food products, are not significant at the five percent level. These results provide an indication of the relative importance of the indirect effects related to profit in these data and for these policies. Thus, at first glance, designing agro-pastoral policies so that they can raise pastoral profit may seem to be a good idea, supported by the significant indirect effects associated with this mediator. Unfortunately, the direction of these indirect effects on dietary intake is probably not the one intended, with perverse negative consequences for total calories in particular. Moreover, this shortcoming is not offset by the direct effects, which are generally not significant.

Table 6b: Mediation model for private veterinary services

	Panel A: 2SLS/OLS			
	Outcomes			
	Log of household dietary diversity score	Log of total calorie intake per day and per capita	Log of calorie intake per day and per capita from cereals	Log of calorie intake per day and per capita from animal food products (OLS)
Mediator				
Log of annual profit from livestock activities	0.423*** (.118) [0.279, 0.810]	-0.711** (.240) [-1.532, 0.359]	-0.939*** (.272) [-1.965, 0.597]	0.413*** (.111)
Policy				
Access to private veterinary services	0.06 (.050)	-0.081 (.158)	-0.121 (.172)	0.229 (.205)
	Panel B: First Stage			
	Mediator			
	Log of annual profit	Log of annual profit	Log of annual profit	Log of annual profit
Policy				
Access to private veterinary services	0.097 (.094)			
Instruments				
Pastoral season (1 if good)	0.32*** (.103)			
Annual maximal temperature in level	-19.375*** (6.154)			
Annual maximal temperature squared	0.275*** (.086)			
Control variables	X	X	X	X
Test of exogeneity of log profit (Robust F)	[0.00]	[0.00]	[0.00]	[0.99]
Test of over identifying restriction: Chi square test	[0.11]	[0.14]	[0.10]	-
F-statistic for first stage excluded instruments	9.04	9.04	9.04	-
Robust test for weak instruments: Effective F-statistic, MP test [Critical value at level 10 percent]	13.46 [13.70]	13.46 [13.70]	13.46 [13.70]	-
R square	-	-	-	0.12
Number of observations	595	595	595	516

Notes: Values in brackets are critical p-values, and values in parentheses are robust standard errors. *, ** and *** imply significance at the 10%, 5% and 1% levels, respectively. The robust test for weak instruments is proposed by Olea Montiel & Pflueger (2013) and computed using a Stata package made available by Pflueger and Wang (2015). MP: Olea Montiel and Pflueger. The confidence interval in brackets is the identification-robust LC_2sls 95 percent confidence interval for linear IV. These confidence intervals are computed using the package twostepweakiv proposed by Sun (2018). The distortion cutoff level obtained from this test is 13%, 8% and 9% for the model of dietary diversity score, total calories intake and calories intake from cereals, respectively, which does not reject the possibility of a weak instrument.

Table 6c: Mediation model for low-cost feed

	Panel A: 2SLS/OLS			
	Outcomes			
	Log of household dietary diversity score	Log of total calorie intake per day and per capita	Log of calorie intake per day and per capita from cereals	Log of calorie intake per day and per capita from animal products (OLS)
Mediator				
Log of annual profit from livestock activities	0.418*** (.115) [0.279, 0.815]	-0.748 ** (.242) [-1.570, 0.396]	-0.985*** (.276) [-2.023, 0.586]	0.408*** (.110)
Policy				
Access to low-cost livestock feed	0.138** (0.057)	0.289* (.175)	0.339* (.200)	0.350* (.184)
	Panel B: First Stage			
	Mediator			
	Log of annual profit	Log of annual profit	Log of annual profit	Log of annual profit
Policy				
Access to low-cost livestock feed	0.175 (.125)			
Instruments				
Pastoral season (1 if good)	0.314*** (.087)			
Annual maximal temperature in level	-20.188*** (6.50)			
Annual maximal temperature squared	0.286*** (.090)			
Control variables	X	X	X	X
Test of exogeneity for log profit: Robust F	[0.00]	[0.00]	[0.00]	[0.97]
Test of over identifying restriction: Chi square test	[0.12]	[0.18]	[0.15]	-
F-statistic for first stage of excluded instruments	8.88	8.88	8.89	-
Robust test for weak instruments: Effective F-statistic, MP test [Critical value at bias=10%]	13.13 [13.92]	13.13 [13.92]	13.13 [13.92]	-
R square	-	-	-	0.13
Number of observations	595	595	595	516

Notes: Values in brackets are critical p-values, and values in parentheses are robust standard errors. *, ** and *** imply significance at the 10%, 5% and 1% levels, respectively. The robust test for weak instruments is proposed by Olea Montiel & Pflueger (2013) and computed using a Stata package made available by Pflueger and Wang (2015). MP: Olea Montiel and Pflueger. The confidence interval in brackets is the identification-robust LC_2sls 95 percent confidence interval for linear iv. These confidence intervals are computed using the package twostepweakiv proposed by Sun (2018). The distortion cutoff level obtained from this test is 13%, 10% and 11% for the model of dietary diversity score, total calories intake and calories intake from cereals, respectively, which does not reject the possibility of a weak instrument.

V.4. The direct and indirect effects of the considered policies on dietary intake

We now conclude the discussion. The estimated total, direct and indirect effects of the considered policies on dietary intake are recapitulated in Table 7. Livestock extension services represent the only policy with a significant impact on profits from livestock activities, and therefore, this is the only policy for which the decomposition of the total effect is relevant. All the indirect effects of livestock extension services are significant, at the 5 percent level, for the four dietary intake indicators. The size of these effects varies across the four outcomes. The estimates show that 69 percent of the effect of livestock extension services on the household dietary diversity score operates through profits. Additionally, 66 percent of the surprising negative effect of livestock extension services on a household's calorie intake from cereals is explained by the annual profit, while the direct effect on this outcome is not significant.

Table 7: Decomposition of the total effect of livestock extension services on dietary intake

| | *Livestock extension services* | | | |
	TE	*IE*	*DE*	*IE/TE*
Outcomes				
Log of household dietary diversity score	0.143*** (0.03)	0.099** (0.05)	0.03 (.06)	0.69
Log of total calorie intake per day and per capita	-0.281** (0.13))	-0.164** (.09)	-0.085 (.18)	0.58
Log of calorie intake per day and per capita from cereals	-0.327*** (0.14)	-0.217** (0.11)	-0.08 (.20)	0.66
Log of calorie intake per day and per capita from animal food products	0.261 (0.19)	0.096** (.05)	0.141 (.21)	-

Notes: TE= Total average treatment effect, IE= Indirect average treatment effect through the annual livestock profit and DE= Direct average treatment effect. DE represents the part of the total effect that does not operate through the annual livestock profit, which is obtained in the mediation model. The values in parentheses are standard errors. The standard errors for IE are computed using simulations. This test is similar to the delta method. *, ** and *** indicate significant differences at the 10%, 5% and 1% levels, respectively.

Through the positive effect on profit, livestock extension services increase the dietary diversity score by almost 10 percent. Moreover, again through this positive effect on profit, livestock extension services decrease calorie intake from cereals by 21.7 percent, while they raise calorie intake from animal products by 9.6 percent. This amounts to reducing total calorie intake by 16.4 percent, which represents 58 percent of the total effect of livestock extension services on this outcome.

The pastoral profit therefore not only appears to be a substantial mediator of the effect of livestock extension services on pastoralist households' dietary intake but also provides hints about the causes of the decline in calorie intake. Nevertheless, this policy met its first objective of improving pastoralist household profits and, furthermore, increasing household dietary diversity.

In contrast, the other two policies, private veterinary services and low-cost livestock feed, did not significantly meet their objective of improving pastoral profits, although their total effect on dietary diversity is significantly positive. Their indirect effects on the dietary diversity score are nonsignificant and small, while only the direct effect of the low-cost livestock feed program on dietary diversity is significant. This suggests that profits are not a mediator of the effects of these policies, especially for the low-cost feed program, or that these policies have too small power for mediation to be apparent.

Let us consider the plausible mechanisms for the direct effects (i.e., nonprofit) of the subsidy program. These effects may be conveyed by channels such as pastoralist household networks or through income sources other than pastoral profits. For example, households may not use the livestock feed they receive to feed their animals, but instead, they may resell it or give it to friends or relatives. Moreover, when they sell it, the received cash may be used to buy food products. When they give it away, they may receive food products in return. Therefore, even without increasing pastoral profit, the low-cost livestock feed program could enhance household dietary intake by generating income or triggering reciprocal food gifts.

Livestock extension services may facilitate household access to livestock products and input markets and therefore should better link the production and consumption of animal products through pastoral profits. However, given that calories are surely a normal good in this context, the effect of pastoral profit on reducing calorie consumption would rather suggest rejecting separable agricultural household models in favor of complex non-separable mechanisms involving thorough lifestyle changes.

VI. Conclusion

In this paper, we investigate and estimate the effects on household dietary intake of three national agro-pastoral policies in Niger (livestock extension services, private veterinary services, and subsidies for low-cost livestock feed). We decompose the average treatment effect of each of these policies into an indirect effect—the part of the total effect that operates through pastoral profit—and a residual direct effect, i.e., the part of the total effect that is channeled through other factors. In this analysis, the profit may be considered stricto sensu, or, alternatively, as a mere proxy for the shadow value of pastoral net output in the context of imperfect markets.

The results show that while they have no significant direct effects, livestock extension services have a positive and significant indirect effect on household dietary diversity. However, their indirect effect, through pastoral profit, on households' total calorie intake is negative, presumably because households substitute a small rise in calorie intake from animal food products for a large decline in calorie intake from cereals. By operating through pastoral profits, livestock extension services foster pecuniary incentives for the specialization of households in pastoral activities, sometimes pushing them toward frequent transhumance or nomadism in an extreme case, a full lifestyle change, which reduces their total calorie consumption since most calories come from cereals. This finding is partially consistent with pastoral profit while substantially mediating the impact of livestock extension services on household calorie intake and dietary diversity. In contrast, pastoral profits are not found to mediate the effects of veterinary services and low-cost livestock feed programs on dietary intake. For these policies, other unobserved channels, such as social networks and other income mechanisms, could have affected dietary intake. However, direct effects are never found to be significant, except marginally, at the ten percent level, for the effect of input subsidies on dietary diversity.

Overall, the estimation results show that policies primarily designed to raise pastoral income can substantially although only partially contribute to enhancing household dietary diversity and calorie intake from animal food products for Nigerien pastoralists. However, they may also severely deplete the calorie intake

from cereals. To avoid this perverse consequence, policy designers should better account for agro-pastoralists' access to cereal markets and whether the policies generate differentiated incentives in favor of a nomadic or sedentary lifestyle. Indeed, when facing new policies, these households may shift productive activities to specialize in pastoralist activities, which may change their way of life and restrict their access to certain food markets, particularly when they engage in frequent pastoral transhumance.

The mediation analysis presents several specific insights. First, our main policy of interest, that is, livestock extension services, exhibits a high relative contribution of the indirect effects based on profit, while the residual direct effects are nonsignificant. In particular, this suggests that policies aimed at raising pastoral profits have significant consequences for dietary intake and therefore for nutritional status. Second, it shows that the direction of these indirect effects on calorie intake is not the one probably intended and that this shortcoming is not offset by negligible direct effects of this policy. Finally, the mediation analysis allows us to understand that the perverse effect of this policy on calorie intake is likely to be related to economic incentives that disrupt joint lifestyle and production choices.

Of course, our findings are dependent on the assumptions made, especially those related to measurement errors in calorie intake data. A typical assumption is that these measurement errors are additive and random, although this assumption may be strong. Another limit to statistical mediation analysis is the possible confusion between changes in the production technology and changes in unobserved inputs when the latter are correlated with observed inputs. Moreover, the exploitation of cross-sectional observational data relies on an ignorability condition, which cannot be tested and may be strong. All these limitations suggest extending this investigation with data from more intensive surveys, in particular those following households over time. Finally, future research, based on richer data, should extend to agricultural mediator variables in addition to pastoral profit and assess other channels through which policies may affect household dietary intake, such as observable changes in activity specialization.

REFERENCES

Amrit K., Pandey R.P., Mishra S.K., Daradur M. (2018). Relationship of drought frequency and severity with range of annual temperature variation. *Nat Hazards* **92,** 1199–1210.

Andrews, I. (2018). Valid Two-Step Identification-Robust Confidence Sets for GMM. *Review of Economics and Statistics* 100(2): 337–348.

Atkinson C. A. (1982). Regression diagnostics, Transformations and Constructed Variables. *Journal of the Royal Statistical Society. Serie B (Methodological).* Vol44. No 1. Pp.1-36.

Ballo, M. and Bauer, J-M. (2013). The Economics of Early Response and Resilience in Niger. Country study. *Department of International Development. UK GOUV.*

Benjamin, D. (1992). Household Composition, Labor Markets and Labor Demand: Testing for Separation in Agricultural Household Models. *Econometrica*, 60, no. 2, 287-322.

Brück, T; O.M. Diaz Botia; N.T.N Ferguson; J. Ouédraogo; Z. Ziegelhoefer (2018). Assets for Alimentation? The nutritional impact of Assets-based programming in Niger. *HICN Working Paper 275.*

Bruffaerts C., Verardi V. and Vermandele (2014). A Generalized Boxplot for Skewed and Heavy-Tailed Distributions. *Statistics & Probability Letters.* Volume 95. Pages 110-117.

Carletto, G., Ruel, M., Winters, P., and Zezza, A. (2015). Farm-Level Pathways to Improved Nutritional Status Introduction to the Special Issue. *The Journal of Development Studies,51(8),* 945-957.

Croppenstedt, A., and Muller, C. (2000). The Impact of Farmers' Health and Nutritional Status on Their Productivity and Efficiency: Evidence from Ethiopia. *Economic Development and Cultural Change, 48*(3), 475–502.

Dawson, N., Martin, A., and Sikor, T. (2016). Green Revolution in Sub-Saharan Africa: Implications of Imposed Innovation for the Wellbeing of Rural Smallholders. *World Development, 78*, 204–218.

De Brauw, A., Eoeznou, P., Gilligan, D. O., Hotz, C., Kumar, N., and Meenakshi, J. V. (2018). Biofortification Crop Adoption And Health Information: Impact Pathways In Mozambique And Uganda. *American Journal of Agricultural Economics*, (May), 906–930.

Dillon, A., McGee, K., and Oseni, G. (2015). Agricultural Production, Dietary Diversity and Climate Variability. *The Journal of Development Studies*, *51*(8), 976–995.

Food and Agricultural Organisation. (2016). Protection Sociale Au Sahel Et En Afrique De L'Ouest Renforcer la résilience au service de la securité alimentaire et de la nutrition.

Fratkin, Elliot, Martha Nathan, and Eric Roth. (2006). Is Settling Good for Pastoralists? The Effects of Pastoral Sedentarization on Children's Nutrition, Growth, and Health Among Rendille and Ariaal of Marsabit District, Northern Kenya. *Presentation for "Pastoralism and Poverty Reduction in East Africa: A Policy Research Conference".* Nairobi, Kenya: International Livestock Research Institute.

Haan, D. (2016). Prospects for Livestock- Based Livelihoods in Africa's Drylands. The World Bank Group,Washington DC.

Heckman, B. J., Pinto, R., Savelyev, P., Blair, C., Benjamin, D., Browning, M., ... Meghir, C. (2013). Understanding the Mechanisms Through Which an Influential Early Childhood Program Boosted Adult Outcomes. *American Economic Review*, *103*(6), 2052–2086.

Heckman, J. J., and Pinto, R. (2015). Econometric Mediation Analyses: Identifying the sources of the treatment effects from experimentally estimated production technologies with unmeasured and mismeasured inputs. *Econometric Review, 34(1-2)*, 6–31.

Herforth, Anna, and Jody Harris. (2014). Understanding and Applying Primary Pathways and Principles. Brief #1. Improving Nutrition through Agriculture Technical Brief Series. Arlington, VA: USAID/Strengthening Partnerships, Results, and Innovations in Nutrition Globally (SPRING) Project.

Imai, K., Keele, L., Tingley, D., and Yamamoto, T. (2011). Unpacking the Black Box of Causality: Learning about Causal Mechanisms from Experimental and Observational Studies. *American Political Science Review*, *105*(4), 765–789.

International Livestock Centre for Africa, I. (1988). Livestock production in tsetse affected areas of Africa. *The African Trypanotolerant Livestock Network*. Nairobi.

Kosec, K., Ghebru, H., Holtemeyer, B., Mueller, V., and Schmidt, E. (2018). The Effect Of Land Access On Youth Employment And Migration Decisions: Evidence From Rural Ethiopia. *American Journal of Agricultural Economics*, Vol. 100(3), 931-954.

Laceteva, N. (2019). Impact of climate change on animal health and welfare. *Animal Frontiers,* January, Vol.9,No.1,26-31

Law, C., I. Fraser and M. Piracha (2020). Nutrition Transition and Changing Food Preferences in India. *Journal of Agricultural Economics,* vol. 71, N. 1, 118-143.

Le Point (2019). Niger : Les éleveurs Touaregs se reconvertissent à l'agriculture. *Article de Presse parue le 15 Novembre 2019.* https://www.lepoint.fr/monde/niger-des-eleveurs-touaregs-se-reconvertissent-dans-l-agriculture-15-11-2019-2347561_24.php

MacKinnon, D. P., Lockwood, C. M., and Williams, J. (2004). Confidence limits for the indirect effect: Distribution of the product and resampling methods. *Multivariate Behavioral Research,* 39, 99-128.

Ministère de l'Elevage, M. (2015). Guide national : Mise en place des Services Vétérinaires Privés de Proximité (SVPP) au Niger, Niamey.

Ministère de l'Elevage, M. (2016). Enquete sur les revenus et la vulnérabilité des ménages agropastoraux et pastoraux, Niger, Niamey.

Muller, C. (2009). Do agricultural outputs of autarkic peasants affect their health and nutrition? Evidence from Rwanda. *Food Policy,*34,166-175.

Muller, C. (2014). A Test of Separability of Consumption and Production Decisions of Farm Households in Ethiopia. *Journal of Poverty Alleviation and International Development,* Volume 5, Number 1, pp. 1-18, June.

Olea Montiel, J. L. and Pflueger, C. (2013). A robust test for weak instruments. *Journal of Business & Economic Statitistics*, *31*(3), 358–369.

Pflueger, C. **and Wang S.** (2015). A Robust Test for Weak Instruments in Stata. *Stata Journal,* 15(1):216-225.

Puentes E.,F. Wang, J.R. Behrman,F. Cunha, J. Hoddinott, J.A. Maluccio, L.S. Adair, J.B. Borja, R. Martorell, A.D. Stein. (2016). Early life height and weight production functions with endogenous energy and proteins inputs. *Economic and Human Biology*. Vol.22, 65-81.

Stadlmayr, B., Charrondiere, R., Enujiugha, V., Bayili, R., Fagbohoun, E., Samb, B., … Burlingame, B. (2012). *West African food composition table [Table de composition des aliments d´Afrique de l´Ouest,* Food and Agricultural Organization.

Sun, L. (2018). Implementing Valid Two-Step Identification-Robust Confidence Sets for Linear Instrumental-Variables Models. *The Stata Journal*, 18(4), 803–825.

Swindale, A., and Bilinsky, P. (2006). Household Dietary Diversity Score (HDDS) for measurement of household food access: Indicator guide. *Food and Nutrition Technical Assistance.* USAID.

The World Bank, (2007). From Agriculture to Nutrition: Pathways, Synergies and Outcomes. *World Development Report 2008: Agriculture for Development. Washington*, DC: The World Bank

United State Agency for International Development, U. (2011). Agriculture And Food Security Niger Fact Sheet. USAID.

Vanderweele, T. J. (2015). Explanation In Causal Inference Methods for Mediation and Interaction. Oxford University Press.

van Wessenbeeck, C.FA., M. A. Keyzer and M. Nubé (2009). Estimation of undernutrition and mean calorie intake in Africa: methodology, findings and implications. *International Journal of Health and Geography*, Vol. 8, N. 37.

Verardi V. and Vermandele C. (2018). Univariate and Multivariate Outlier Identification for Skewed Heavy-Tailed Distributions. *Stata Journal.* Vol18. No3. pp 517-532.

Vicente-Serrano S. M., J. I. Lopez-Moreno, S. Begueria, J. Lorenzo-Lacruz, A. Sanchez-Lorenzo, J. M. Garcia-Ruiz, C. Azorin-Molina, E. Moran-Tejeda, J. Revuelto, R. Trigo (2014). Evidence of increasing drought severity caused by temperature rise in southern Europe. *Environ. Res. Lett.* *9 044001*

Wooldridge, J. M. (2007). Inverse Probability Weighted Estimation for General Missing Data Problems. *Journal of Econometrics*, *141*(2), 1281–1301.

Wooldridge, J.M. (2010). Econometric Analysis of Cross Section and Panel Data. MIT Press, Princeton.

Zezza, A., and Issa, A. (2012). Livestock in Niger: an important asset for growth and poverty reduction. *Livestock data innovation in Africa brief* ; issue no. 7. Washington DC ; World Bank Group.
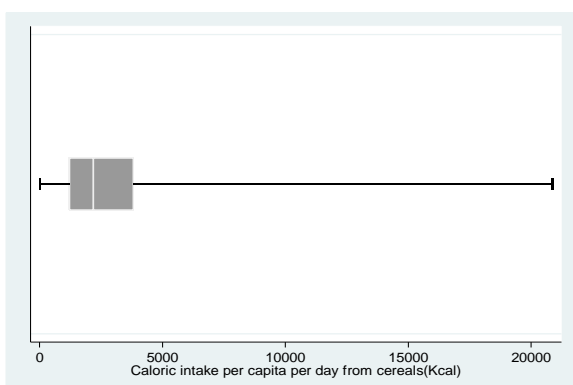
Appendix 1: Generalized boxplots of calorie intake
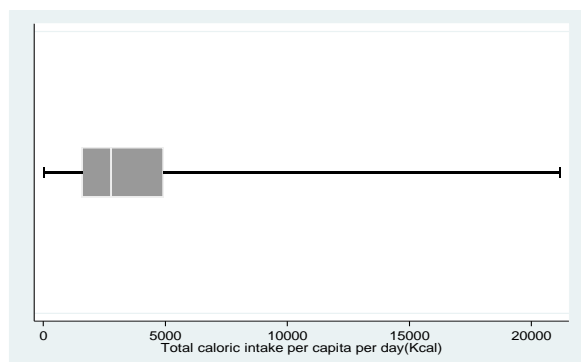
(a)   Total calorie intake per capita per day
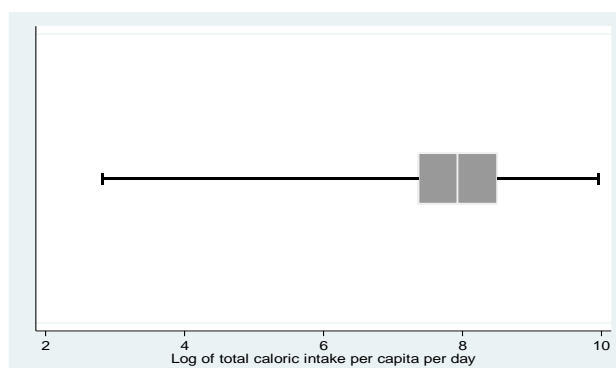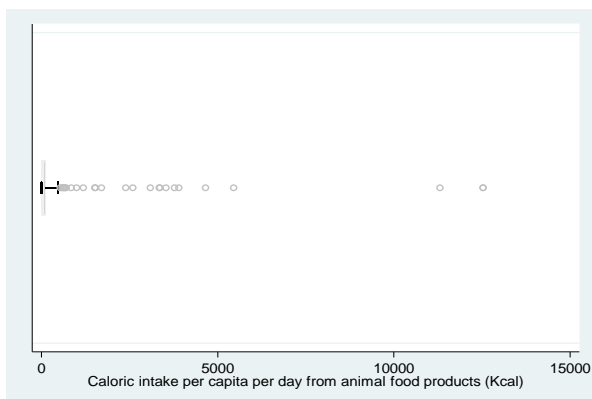

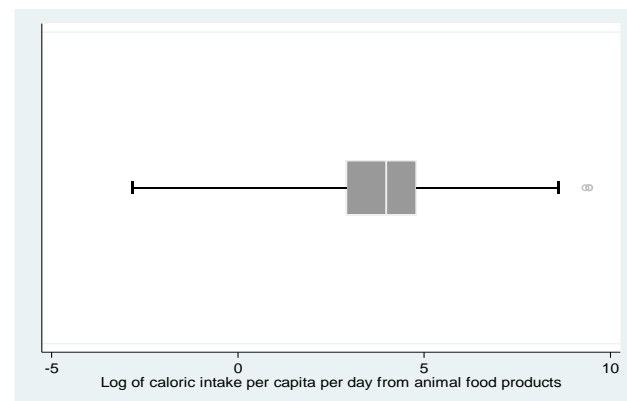(b)   Log of total calorie intake per capita per day

(c) Calorie intake per capita per day from cereals

(d)   Log of calorie intake per capita per day from cereals

(e)   Calorie intake per capita per day from animal food products

(f)   Log of caloric intake per capita per day from animal food products

Appendix 2: Comparison of pastoral and agropastoral household dietary intake during pastoral mobility

Outcomes (mean values of logarithms)	Agropastoral households (N=557)			Pastoral households (N=43)		
	No Pastoral Mobility (N=444)	Pastoral Mobility (N=113)	Diff	No Pastoral Mobility (N=23)	Pastoral Mobility (N=20)	Diff
Total calorie intake per capita per day	7.728 (.062)	7.389 (.136)	.339*** (.141)	9.203 (.072)	7.900 (.185)	1.302*** (.189)
Calorie intake per capita per day from cereal products	7.495 (.063)	7.050 (.147)	.445*** (.146)	9.030 (.077)	7.414 (.152)	1.616*** (.164)
Calorie intake per capita per day from animal food products	3.661 (.091)	3.767 (.183)	-.105 (.202)	4.107 (.264)	5.679 (.419)	-1.571*** (.527)
Household dietary diversity score	1.570 (.021)	1.704 (.030)	-.133*** (.045)	1.628 (.056)	1.963 (.033)	-.335*** (.068)
Annual profit from livestock production	14.606 (.048)	15.001 (.080)	-.395*** (.103)	15.067 (.135)	16.181 (.282)	-1.114*** (.300)

Appendix 3: Comparison of the control group and the treated group on the basis of covariates used in the IPWRA model

a) Baseline comparison

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

Notes: Values in parentheses are variances

b) Comparison after weighting with IPWRA

Covariates for IPWRA (mean values)	Livestock extension services		Low-cost livestock feed		Private veterinary services	
	Raw standardized difference	Weighted standardized difference	Raw standardized difference	Weighted standardized difference	Raw standardized difference	Weighted standardized difference
Sex of household head (1 if female)	-.14 (.47)	.02 (1.11)	-.16 (.42)	-.04 (.81)	-.15 (.47)	-.09 (.62)
Age of household head (in years)	-.05 (.93)	-.01 (1.01)	.16 (1.00)	.01 (.94)	-.07 (.88)	.01 (.97)
Area of living (1 if in the South)	.24 (.87)	-.00 (1.00)	-.07 (1.03)	-.00 (1.00)	-.44 (1.08)	.11 (.93)
Proportion of children (0-3 years old)	.08 (1.07)	.01 (1.12)	.02 (1.08)	-.02 (1.08)	.24 (1.01)	-.08 (.85)
Proportion of children (4-10 years old)	.13 (.86)	.01 (.98)	.23 (.97)	.02 (1.01)	.21 (.81)	-.15 (.99)
Proportion of youths (11-16 years old)	.15 (1.26)	-.04 (1.16)	-.00 (1.06)	-.00 (1.00)	.16 (1.21)	-.04 (1.07)
Proportion of young adults (17-20 years old)	-.08 (1.03)	.00 (1.24)	-.21 (.64)	-.03 (.79)	-.12 (.62)	-.15 (.64)
Ethnic group						
- Tuareg (1 if yes and 0 otherwise)	-.09 (.88)	-.03 (.94)	.14 (1.18)	-.03 (.96)	.16 (1.20)	-.06 (.91)
- Fulani (1 if yes and 0 otherwise)	.18 (.95)	-.01 (1.00)	.02 (1.00)	.04 (.98)	-.52 (.95)	.08 (.97)
- Haussa (1 if yes and 0 otherwise)	-.15 (.71)	.05 (1.10)	-.19 (.63)	-.03 (.92)	-.00 (1.00)	-.02 (.94)
Instruction level of household head						
- None (1 if yes and 0 otherwise)	-.03 (1.16)	-.07 (1.31)	-.01 (1.07)	-.03 (1.13)	-.11 (1.56)	.06 (.75)
- Primary (1 if yes and 0 otherwise)	.02 (1.11)	.08 (1.41)	.03 (1.17)	.06 (1.33)	.01 (1.09)	-.06 (.70)

Notes: Values in parentheses are variances ratio

c) **Overlapping assumption**