Title: Is poverty a constraint to the adoption of sustainable diet? The case of meat consumption in France.

Keywords: Meat; socioeconomic status; body mass index; overweight; diet quality.

Long abstract: *Regulating meat consumption appears as a relevant public policy to limit food-related carbon footprint. The existing literature in public health also suggests that a decrease in meat intake, due to a tax implementation for instance, might be beneficial for human health and nutrition, decreasing the risk of obesity and related chronic diseases, and so on to reduce public health expenditures. Nonetheless, recent experiments based on randomized control trials cast doubt about the validity of these results. In fact, most of previous cohort studies observing a link between meat consumption and nutritional outcomes focused on specific subpopulations characterized by higher levels of education, higher incomes, and higher rates of women. This lack of representativeness in the data justifies therefore the need to reexamine the association through the prism of economics by exploring potential effects specific to household socioeconomic status (SES). Focusing on the French adult population in 2015, we thus performed multivariate linear regressions estimating potential trend differences in the association between meat consumption and nutritional outcomes according to educational achievement. We found that among low-educated households, one kilogram less of meat consumption per month was significantly associated with a higher individual BMI (0.87±0.04 kg/m²), a higher risk of overweight (0.95±0.38 percentage point), and higher intakes of ultra-processed food (4.10±1.57 percentage points), sweet drinks (58.42±20.46 g), and sugar (12.60±4.18 g). By contrast, the association was positive for the most educated individuals. These results are robust to several measurements of educational attainment and SES, including household income, occupation, and financial insecurity perception. We conclude that individuals with higher SES may be more prone to replace meat by healthy alternatives, whereas those with lower SES may tend to replace meat by ultra-caloric food and beverage, especially dense in sugars. In terms of contribution for science and society, this study is the first to show that SES changes the relationship between the amount of meat consumption and nutritional outcomes in a nationally representative sample. Our findings call for future research on this topic to provide actionable recommendations for implementing a fair and healthy protein transition.*

Short abstract: *In a context of a growing advocacy for reducing meat consumption in Western countries, we test if populations with a low level of education are more likely to replace meat by less healthy alternatives, which could reduce dietary quality and have negative effects on nutritional outcomes such as weight gain. Focusing on the French adult population, we performed multivariate linear regressions estimating potential trend differences in the association between meat consumption and nutritional outcomes according to educational achievement. We found that among low-educated households, one kilogram less of meat consumption per month tended to be associated with a higher individual BMI (0.87±0.04 kg/m²), a higher risk of overweight (0.95±0.38 percentage point), and higher intakes of ultra-processed food (4.10±1.57 percentage points), sweet drinks (58.42±20.46 g), and sugars (12.60±4.18 g). By contrast, the association was positive for the most educated individuals. These results are robust to several measurements of SES. In terms of contribution for science and society, this study is the first to show that SES changes the relationship between the amount of meat consumption and nutritional outcomes in a nationally representative sample. Our findings call for future research on this topic to provide actionable recommendations for implementing a fair and healthy protein transition.*

Word-count: around 6000 words.

1. Introduction

Regulating meat consumption appears as a relevant public policy to limit food-related carbon footprint and reduce public health expenditures (Springmann et al., 2016; Boutron-Ruault et al., 2017).[1] In case of the implementation of regulatory instruments in the meat market, such as tax and quality norms, an increase of meat price for consumers is then expected as well as a diet rebalancing.[2] Note that these policy reforms are likely to take place in a context of climate change leading to a sustained inflation of international meat price namely because of a higher frequency of poor harvests in cattle feed, such as soy, wheat, and corn (Reynolds, 2010).

At first sight, an increase in meat price, implying a decrease in its consumption, seems beneficial for the planet, but also for human health and nutrition. Overconsumption of meat is a widespread issue in high-income countries, including France, where average individual consumption of animal products exceeds the international requirements and recommendations (Joint FAO/WHO/UNU, 2007). The epidemiological literature comparing vegetarian and non-vegetarian diets using cohort data suggests that meatless diets reduce body mass index (BMI), food-related non-communicable diseases (e.g., cancers, heart diseases, and diabetes mellitus), and overall mortality (Le and Sabaté, 2014; Dinu et al., 2017), especially when plant-based diets are healthy (Satija et al., 2019). Hence, potential protective effects of the diet's vegetablization against weight gain appear as particularly promising when considering the rising global epidemic of obesity.

Nonetheless, these protective effects are not confirmed by experiments based on randomized control trials (RCT). Indeed, a recent meta-analysis cumulating 19 RCTs with a median duration of 12 weeks shows that participants assigned to meat- and/or dairy-reduced diet had a lower protein intake compared to control diets, but no significant gap was observed regarding bodyweight outcomes and fat composition (Habumugisha et al., 2023). In fact, most of cohort studies observing a link between meat consumption and nutritional outcomes focused on specific subpopulations characterized by higher levels of education, higher incomes and higher rates of women. This lack of representativeness in the data may result in a

[1] Livestock farming, especially the beef sector, causes higher greenhouse gas emissions than other agricultural activities, and cutting red meat in the diet is thus one possible way to reduce the environmental impact of the food system (Springmann et al., 2016). High consumption of red meat and processed meat is also suspected to increase the prevalence of overweight and obesity, as well as the risk of type 2 diabetes, stroke, colorectal cancer, and all-cause mortality (Boutron-Ruault et al., 2017).

[2] Already today, national dietary guidelines are starting to include recommendations for upper levels of meat intake. In France for example, the recommended maximum intake of red meat is 500g per week and that of processed meat is 25g per day (ANSES, 2016).

sample selection bias contributing to overstate the protective nutritional impacts of meatless diet. It is indeed likely that richer and more educated individuals have a higher interest for health and nutrition, and thus a higher willingness to adopt healthier behavior and general diet than poorer and less educated individuals.[3]

Potential sample selection biases in previous studies justify the need to reexamine the association between meat consumption and nutritional outcomes by focusing on potential heterogeneity according to household socioeconomic status (SES). Indeed, since higher SES (e.g., generally measured by educational attainment, household income, and occupational status) are significantly associated with healthier eating habits, including increased consumption of fruits, vegetables, and whole grain foods (Darmon and Drewnowski, 2008), one may assume that SES influences meat substitutes in a context of lower meat intake, and then results in different nutritional outcomes. In Western countries, meat remains an important source of dietary protein and of indispensable nutrients including vitamin B12, zinc and iron, and it is therefore important to consider the impact that reducing meat consumption could have on the diet quality of lower socioeconomic segments of the population. One may indeed hypothesize that the lack of significant effect in RCTs testing the bodyweight impact of reduced-meat diet could be due to an offsetting effect: meatless diet might be protective for individuals with higher SES and detrimental for individuals with lower SES. Theoretically, the nutritional impacts of a vegetablization of diet strongly are expected to depend on meat substitution strategies operated by individuals. Replacing animal protein with plant-based products favors the nutritional adequacy of the diet when the plant protein comes from foods of high nutritional value such as whole grains, nuts, seeds, legumes, and vegetables (Salomé et al., 2020). In contrast, diets rich in affordable "unhealthy" plant foods (e.g., fruit juices, sweetened beverages, refined grains, fried potatoes, sweets, and desserts) are associated with increased risk of weight gain, type 2 diabetes, and coronary disease over time (Satija et al., 2019, 2017, 2016). A prevailing low-quality diet may encourage replacing meat by (affordable) foods of lower nutritional quality, so it is therefore important to consider the socioeconomic context in which the reduction in meat consumption takes place. In this study, we hypothesize that meat substitution strategies are directly influenced by SES. Because of economic and cultural constraints, low-SES populations might be more likely than high-SES populations to replace meat with fat and carbohydrates, since many alternative sources of

[3] For example, the NutriNet-Santé cohort (France) and the Adventist cohorts (US and Canada) only includes voluntary participants, resulting in an overrepresentation of educated and female individuals. A similar sample bias may be attributed to the study of Satija et al. (2019) that focuses on a very specific population group working in the medical field.

protein (including fish, dairy products, and plant proteins) are more expensive and (geographically and culturally) less accessible than high-fat and high-sugar foods. These behaviors might further increase the risk of diet-related disease among low-SES populations already highly affected by overweight and obesity. To avoid an increase in nutritional inequality, there is a need to better understand the potential nutritional impacts of reducing meat consumption for different SES groups.

Based on a representative adult sample from France (INCA3, 2015), this article firstly proposes to explore potentials gaps in nutritional outcomes across education groups when meat consumption varies in diet. Specifically, we econometrically test if individual education modify the association between meat consumption and nutritional outcomes, considering body mass index (BMI measured in kg/m²) and its classification (overweight versus non-overweight), diet indicators (daily energy intake in Kcal/day, and the share of ultra-processed food (UPF) in daily energy intake), risky food/beverage intakes (consumption of sweets, sweet drinks and snacks in g/day), and macronutrients composition of diet (sugars, fats, and proteins in g/day). Our results show that the association between meat consumption and nutritional outcomes is highly dependent on educational attainment. Among the most educated individuals, meat consumption is positively and significantly associated with BMI, overweight status, UPF intake, sweet drinks intake, and sugars intake. By contrast, the opposite is true for individuals with lower levels of completed education. The results are robust to other measurements of SES.

2. Methods

2.1. Data and sample

INCA3 (French National Individual Survey on Food Consumption) is the most recent nationally representative cross-sectional individual survey conducted by the French National Agency for Food, Environment and Occupational Health & Safety (ANSES). It includes data on 3,157 adults aged 18 to 79 and 2,698 children aged 0 to 17 (Dubuisson et al., 2019). This survey is particularly appropriate for our research question insofar as INCA3 has the advantage of providing detailed individual information on reported food and beverage consumption, economic and sociodemographic characteristics, and objective anthropometric measurements (height and weight) made using scales and stadiometers at home. As recommended by the survey administration, our statistical and econometric analyses are balanced using the weights provided in the INCA3 database to make the results representative of the French population.

We restricted our sample to non-pregnant and non-lactating adult individuals and excluded adults over the age of 65. Hence, all our analyses are representative of the French adult population aged from 18 to 64. This restricted sample includes about 1,400 adults.

2.2. Econometric model and variables

Given the cross-sectional structure of the data, we are not able to correct the potential influence of initial diet (before a potential reduction of meat intake) on current diet and BMI, and specifically unable to distinguish long-term meatless diet from short-term meatless diet. One can indeed assume that individuals with low levels of SES and meat intake were initially more likely to gain weight (due to an initial unbalanced diet), and that an additional decrease in meat intake may have only accentuated this trend. Such an endogeneity problem due to the omission of current BMI's determinants may then lead to understate the real impact of a meat reduction in initial diets characterized by an average level of meat intake. Despite this risk of underestimating expected effects, the analysis of INCA3 database can nonetheless give first evidence on the research question in addition to provide intuitions to test in future research.

Our empirical strategy relies on a static model in which we assume that diet balancing and substitution strategies are definitely decided by individuals and are not going to change across time. In other words, we assume that the amount of meat eaten by an individual is associated with a specific diet and a specific nutritional status, that depend on its SES. Specifically, we perform multivariate linear regressions interacting SES indicators and meat consumption measures, and controlling for several covariates. For each considered dependent variable Y_i, we regress the following ordinary least square estimation model:

$$Y_i = \beta_0 + \beta_1 SES_i^j + \beta_2 Meat_i + \beta_3 SES_i^j ¿ Meat_i + \beta_4 X_i + \varepsilon_i$$

Y_i refers to four types of outcomes that allow us to characterize the nutritional profile of individuals *i*. We consider: (i) the individual nutritional status, measured by BMI (in kg/m²) and overweight status (i.e., a binary variable that takes the value 1 if BMI is higher than 25 kg/m², 0 otherwise); (ii) the individual diet, measured by the daily energy intake excluding alcohol intakes (in Kcal/day), and a score of diet quality, measured by the share of UPF in daily energy intake (calculated from the NOVA classification); (iii) the individual intake in risky food and beverage, measured by the consumption of sweet drinks (including soft-drinks and fruit juices), sweets (including bakery products, cakes & biscuits, desserts, ice creams, chocolates & candies, and other sugars), and snacks (including pizza, burgers, sandwich, quiche, and other salted snacks) in g/day; (iv) the individual diet composition in essential macronutrients, measured by sugar (a part of carbohydrates), fat, and protein intakes in g/day.

In the set of independent variables, SES_i^j refers to the SES of an individual *i* and $Meat_i$ refers to the amount of raw meat an individual *i* eats in a month. In order to explore the association between nutritional outcomes and meat consumption according to SES, we introduce an interaction term between the two factors of interest (SES_i^j ¿ $Meat_i$). Thanks to this interaction term, we are able to appreciate if the associations between meat consumption and nutritional outcomes are significantly different from one group *j* of SES to another group *j*.

There are several ways to measure an individual's SES since this concept is multifactorial and includes economic, cultural and social dimensions (Bourdieu, 2002), respectively approximated by household income, educational attainment, and occupation in empirical studies. In this study, we test our model relying on these three dimensions, but only report education-based results in the main document.[4] Educational attainment is measured thanks to a categorical indicator derived from a discrete score measuring the highest diploma obtained by an individual (varying from 1 for never schooled individuals to 12 for postgraduate individuals). Based on this score, three levels *j* of completed diploma are defined (*j=1:* no diploma; *j=2:* a technical or professional diploma, including middle school diploma; *j=3:* at least a high school diploma). Additional estimates based on alternative measurements of SES are reported in Supplementary Materials, by considering three groups of household income based on sample tercile (*j=1:* less than 1,750 €/month; *j=2:* middle incomes; *j=3:* more than 3,850 €/month), four occupation groups based on the international standard classification (*j=1:* workers engaged in occupations requiring manual labor or heavy machinery; *j=2:* workers engaged in skilled or semi-skilled jobs; *j=3:* professionals and workers engaged in executive, administrative or clerical duties; *j=4:* inactive), and a binary variable of financial insecurity perception (*j* takes the value 1 if the respondent declares financial difficulties to end the month, 0 otherwise).

We measure meat consumption in g/month by multiplying the number of days per month an individual consumes raw meat (estimated from a retrospective period of 12 months before the survey) with the number of grams consumed per day (estimated from a 3-day food dairy with a 24h recall). We include in this measurement of raw meat consumption beef, pork, poultry,

[4] Note that the educational dimension is consensually preferred in cross-sectional studies to measure SES since this factor does not vary too much across time among adult populations. By contrast, household income, and at lower extent individual occupation, is preferred in longitudinal studies relying on time-fixed effect models, since both factors are time-varying.

sheep, offal, sausages, terrines, and other mixtures, but exclude dishes that may partially include meat like stew and snacks insofar as the amount of meat in these dishes is highly uncertain. As shown in Figure S1 of Supplementary Materials, this exclusion is unlikely to affect our results given the absence of significant gaps in stew and snack intakes across education groups. Based on a boxplot analysis, we consider as extreme values individuals that declare to consume more than 6kg/month of raw meat, and exclude them from the analysis. Hence, meat consumption varies from 0 to 6 kg/month. Distributions of raw meat consumption across education groups are available in Figure S2 of Supplementary Materials.

In the set of control variables, X_i, we include the main determinants of nutritional outcomes, excluding energy intake which is considered as a dependent variable in the model. Concretely, we control for demographic factors such as age group (18-44, or 45-64), sex, and household composition (number of children and adults), as well as for environmental factors such as the degree of urbanicity of the living area (rural, small city, medium size city, large city, and the Paris agglomeration) and the region of residence. We also control for individual habits including daily smoking (a binary-response variable), an alcohol consumption score varying from 0 to 90 (which is the sum of days/month when an individual consumes wine, days/month when an individual consumes beer, and days/month when an individual consumes cider), and the levels (low, medium, or high) of physical activity (e.g., sport) and sedentary activity (e.g., time spent sitting in front of screens) directly calculated by the INCA administration using average daily time allocated to both types of activity. Furthermore, we systematically control for possible under- and over-reporting using the Goldberg/Black method provided by the INCA3 survey administration.[5] Finally, in regressions in which daily energy intake is considered as dependent variable, we adjust by the basal metabolic rate of an individual.

3. Results

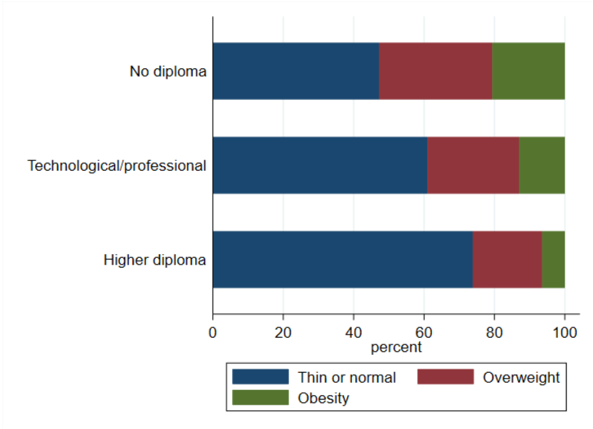
3.1. Descriptive statistics

Table 1 lists weighted sample means for most of explanatory variables among the whole sample, but also among each education group. Compared to others, individuals without formal diploma tend to be older (i.e., 76% belongs to the 45-64 age group) and are characterized by lower meat and alcohol intakes. By contrast, the most educated individuals tend to have more children and a more 'mondain' lifestyle (e.g., living a bit more in large cities, consuming alcohol more frequently, eating lunch less often at home, and being physically more active).

[5] For more information concerning the calculation of these variables, please refer to the survey website and related documents, available on: https://www.data.gouv.fr/fr/datasets/donnees-de-consommations-et-habitudes-alimentaires-de-letude-inca-3/

Comparatively with the most educated individuals, those with technical or professional trainings disproportionally live in rural areas and are less physically active. Based on Figure 1, it is interesting to note that overweight and obesity statuses are the most prevalent among individuals without formal diploma, and the least prevalent among the most educated individuals. This kind of nutritional inequality is consistent with other studies based on France and high-income countries (Darmon, 2008).

Figure 1: BMI classification across education groups



Notes: Lactating and pregnant women were excluded as well as children (<18 yo) and the elderly (>65 yo). The BMI-based classification used is thin or normal (BMI<25kg/m²); overweight (25<=BMI<30kg/m²); obese (>=30kg/m²).
Source: INCA-3 (2014-2015).

Table 1: Descriptive statistics across education groups

	ALL ADULTS (aged 18-64)		NO DIPLOMA (at most attended elementary school)		TECH./PROF. (incl. middle-school diploma)		HIGHER DIPOLOMA (inc. high school and university degrees)	
	Mean	**Std. Err.**	**Mean**	**Std. Err.**	**Mean**	**Std. Err.**	**Mean**	**Std. Err.**
Body mass index (kg/m²)	25.65	0.19	28.28	0.78	*26.35*	0.32	*24.39*	0.22
Overweight status (binary)	0.50		0.76		*0.54*		*0.40*	
Meat consumptions (g/month)	1862	61.25	1574	162	**1880**	93	**1924**	110
Male (binary)	0.48		0.41		0.49		0.50	
Aged 45-64 (binary)	0.45		0.76		*0.50*		*0.33*	
Daily smoking (binary)	0.25		0.30		0.29		*0.19*	
Alcohol cons. index (0-to-90 score)	10.70	0.49	6.53	1.00	**9.72**	0.93	**12.74**	0.66
Medium physical activity (binary)	0.47		0.43		0.59		*0.37*	
High physical activity (binary)	0.16		0.10		0.09		**0.23**	
Medium sedentariness (binary)	0.42		0.50		0.49		*0.34*	
High sedentariness (binary)	0.46		0.41		0.37		**0.55**	
Lunch at home (binary)	0.53		0.74		*0.59*		*0.43*	
Declared as vegetarian (binary)	0.02		0.02		0.03		0.01	
Number of adults per household	2.14	0.04	2.18	0.13	2.22	0.07	2.06	0.07
Number of children per household	0.81	0.05	0.52	0.12	0.73	0.08	**0.97**	0.08
Rural area (binary)	0.26		0.17		**0.36**		0.20	
Small city [2000-20000[(binary)	0.18		0.26		0.19		0.14	
Middle size city (binary)	0.13		0.15		0.15		0.10	
Large city >=100000 (binary)	0.30		0.32		0.22		0.37	
Paris' urban area (binary)	0.14		0.11		0.08		0.19	
OBSERVATIONS	*n=1,318; N=29,354,406*		*n=101; N=3,496,348*		*n=537; N=12,165,691*		*n=671; N=13,378,632*	

Notes: Means and standard errors are weighted using the survey recommendations to guarantee the representativeness of the sample. *N* refers to the population size and *n* refers to the sample size. HH means household. Lactating and pregnant women were excluded as well as children (<18 yo) and the elderly (>65 yo). For each row variable, mean-comparison tests were processed comparing the reference group (the "no diploma" group) with other education groups: positive and significant differences are displayed in bold, and negative and significant differences are displayed in italic. Source: INCA-3 (2014-2015).

3.2. Econometric estimates

Table 2 reports regression results when continuous BMI and overweight status are used as dependent variables. Globally, the models fit relatively well: the explanatory variables capturing 24% of BMI variations across individuals. Moreover, the fitted coefficients of control variables have an expected sign, in accordance with the health economics literature on the determinants of BMI (e.g. Bonnefond and Clément, 2014; Levasseur, 2015; Clément, 2017). Indeed, age, a low level of physical activity, the sedentariness index, and family size, are positively associated with BMI and overweight.

Regarding the fitted coefficient of the interaction term (in bold in Table 2), the sign and significance seem to confirm our hypothesis. Estimates indicate that among the most educated individuals, one extra kilogram of meat consumption in a month is significantly associated with a higher individual BMI, by 0.87 kg/m² on average, and a higher risk of being classified as overweight, by 0.95 percentage point on average, compared to individuals with no diploma ($P<0.05$). Figure 2 plots the fitted marginal effects (at mean points) of meat consumption on adult BMI for each education group (based on fitted coefficients from Table 2). This figure perfectly illustrates the existence of an education level-specific association between meat consumption and BMI, which is significantly positive for the most educated individuals ($P<0.05$), but significantly negative for individuals without diploma ($P<0.05$). For the intermediate group of education (i.e., technical/professional diploma), the trend is flat and non-different from 0.

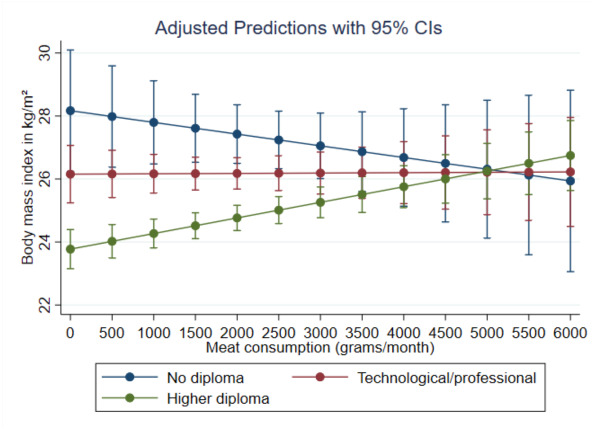
These results are robust to different measurements of SES. In Figure S3 of Supplementary Materials, we report plots of adjusted regressions of BMI on meat consumption by household income groups, occupation groups and financial insecurity perception by the respondent (regression tables are available upon request). We consistently observe that among high-income households, higher meat consumption is significantly associated with higher individual BMI (by 1.03 kg/m² for one extra kg of meat, $P<0.01$) and higher risk of overweight (by 1.13 percentage points for one extra kg of meat, $P<0.01$), compared to low-income households for which the association is negative and significant. Likewise, having a high occupation index tends to increase the positive association between meat consumption and BMI (by 0.54 kg/m² for one extra kg of meat, $P<0.1$), whereas declaring some financial difficulties to end the month significantly decreases the association between meat consumption and BMI (by 0.50 kg/m² for one extra kg of meat, $P<0.05$).

Table 2: Regression of nutritional status on education groups, meat consumption and covariates

	BMI (kg/m²)	Overweight status (=1)
Meat consumption (kg/month)	-0.372	-0.026
	(0.374)	(0.032)
Technological or professional diploma (binary)	-2.014*	-0.239***
	(1.116)	(0.083)
Higher diploma (binary)	-4.394***	-0.413***
	(1.026)	(0.079)
TechPro*MeatCons.	**0.383**	**0.047**
	(0.419)	**(0.040)**
HigherDip*MeatCons.	**0.867****	**0.095****
	(0.405)	**(0.038)**
Male (binary)	0.145	0.069*
	(0.364)	(0.040)
Aged 45-64 (binary)	1.635***	0.202***
	(0.372)	(0.038)
Daily smoking (binary)	-0.573*	-0.022
	(0.341)	(0.040)
Alcohol consumption index (0-to-90 score)	0.011	0.001
	(0.011)	(0.001)
Medium level of physical activity (binary)	-1.120***	-0.118***
	(0.359)	(0.034)
High level of physical activity (binary)	-1.559***	-0.155**
	(0.484)	(0.060)
Medium level of sedentariness (binary)	-0.345	0.014
	(0.556)	(0.052)
High level of sedentariness (binary)	0.823	0.068
	(0.523)	(0.051)
Lunch at home (binary)	0.174	0.044
	(0.308)	(0.033)
Declared as vegetarian (binary)	0.201	0.047
	(1.071)	(0.122)
Number of adults per household	0.428*	0.045*
	(0.231)	(0.027)
Number of children per household	-0.040	-0.007
	(0.160)	(0.017)
Season dummies	YES	YES
Urbanicity levels	YES	YES
Region dummies	YES	YES
Black's misreporting indexes	YES	YES
Constant	26.846***	0.394***
	(1.527)	(0.141)
Observations	1,309	1,309
R-squared	0.237	0.190

Notes: Estimates are weighted using the survey recommendations to guarantee the representativeness of the sample. Lactating and pregnant women were excluded as well as children (<18 yo) and the elderly (>65 yo).
Standard errors are in parentheses. Levels of significance of fitted coefficients: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Source: INCA-3 (2014-2015).

Figure 3: Fitted BMI across household income and education groups



Notes: Estimates are weighted using the survey recommendations to guarantee the representativeness of the sample. Lactating and pregnant women were excluded as well as children (<18 yo) and the elderly (>65 yo). Estimates are adjusted by age, gender, smoking, alcohol consumption, physical activity, sedentariness, number of adults and children in the household, lunch place, vegetarian diet declaration, season of survey, urbanicity, region, and Black's index of under and overreporting. Confidence intervals (CIs) are fixed at the 95% level.
Source: INCA-3 (2014-2015).

To go beyond in our understanding of potential pathways that may explain why low-meat eaters with low SES tend to have a higher BMI and a higher risk of overweight compared to others, Table 3 replicates the baseline regression model for several dependent variables relating to global diet (daily energy intake, and UPF rate), risky food/beverage intakes (sweet drinks, sweets and snack intakes) and macronutrient composition of diet (sugar, fat and protein intakes). We find that, compared to individuals without diploma, the most educated individuals with a high level of meat consumption tend to have a higher daily energy intake (88Kcal by extra kg of meat, P<0.1), but also higher daily intakes of UPF (4 percentage points by extra kg of meat, P<0.01), sweet drinks (58g by extra kg of meat, P<0.01), sweets (10g by extra kg of meat, P<0.1), sugar (13g by extra kg of meat, P<0.01), and protein (4g by extra kg of meat, P<0.05).[6] Note that the lower significance observed for daily energy intake and sweets intake, and also the non-significance regarding snacks and fat intakes, might be due to an under-reporting bias that tends to be larger among the least educated and the most corpulent individuals, and which disproportionally concerns out-of-home food consumptions and snacking (Poslusna et al., 2009; Archer et al., 2013).

Figures 3, 4 and 5 plot the fitted marginal effects (at the mean point) from Table 3 for each education group. Each figure (excepted for snacks and protein intake) shows a clear opposition between the least and the most educated individuals, which is highly consistent

[6] Results based on the income classification were less significant (available upon request).

with our BMI-based findings. Indeed, it appears that among individuals without diploma, eating less meat is positively and significantly associated with daily energy intake, and intakes of UPF, sweet drinks, sweets, sugar and fat, whereas the opposite is true for more educated individuals. Regarding snacks and protein intakes, Figures 2 and 3 indicates similar trends across education groups. However, for higher levels of meat consumption, the level of protein intake (but also snacks intake) is significantly lower among individuals without diploma. This latter result suggests that meat might be a major (even quasi-exclusive) source of protein for less educated individuals who may have a lower propension to consume alternative sources of proteins such as dairy products, legumes, and other vegetal proteins, compared to more educated individuals who may have a more diversified diet. In non-reported analyses, we indeed note higher intakes of dairy products, legumes and vegetal proteins (e.g., soy-based products) among the most educated individuals for upper levels of meat consumption, compared to individuals without diploma.

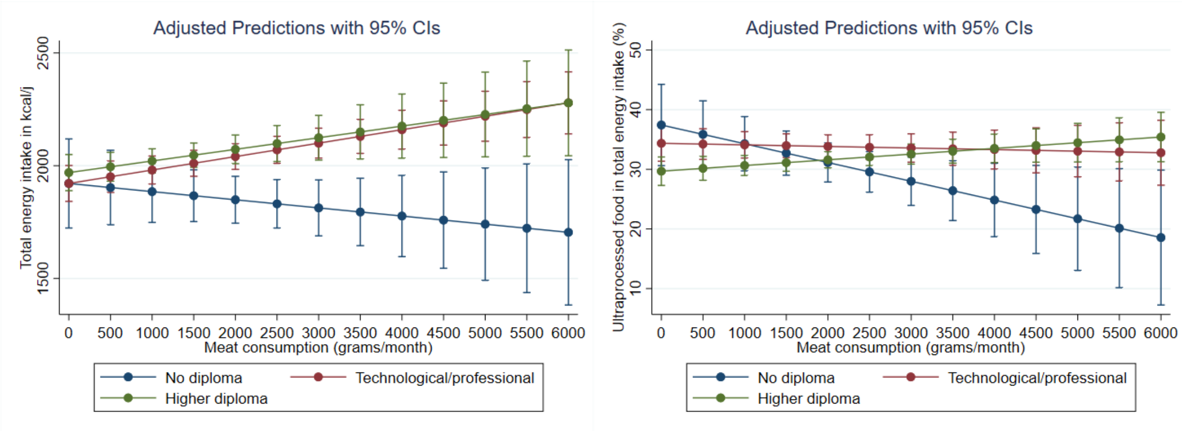
Finally, in Table S1 of Supplementary Materials, we test for each dependent variable considered in the study, alternative estimates based on a discrete measurement of educational attainment (a score varying from 1 to 12). These results confirm most of previous findings from Tables 2 and 3, except for daily energy intake and sweets intake for which the interaction terms are non-significant. Hence, results for both latest outcome variables should be treated with caution.

Table 3: Regression of diet indicators, risky food intake and macronutrient composition on completed education, meat consumption and covariates

	DIET		RISKY FOOD INTAKE			MACRONUTRIENT COMPOSITION		
	Energy intake (Kcal/day)	**UPF intake (% energy intake)**	**Sweetdrinks intake (g/day)**	**Sweets intake (g/day)**	**Snacks intake (g/day)**	**Sugar intake (g/day)**	**Fat intake (g/day)**	**Protein intake (g/day)**
Meat consumption (kg/month)	0.112	-3.070	2.587	-0.959	-8.158	-6.199	3.032	1.270
	(101.943)	(3.806)	(60.433)	(12.570)	(18.269)	(9.351)	(4.627)	(4.189)
Technological or professional diploma (binary)	48.213	-7.750**	-72.790	3.659	-4.710	-5.356	2.481	-2.682
	(105.642)	(3.788)	(46.734)	(13.041)	(17.401)	(10.021)	(4.353)	(4.329)
Higher diploma (binary)	-36.099	-3.146**	-44.024***	-8.994*	-17.302***	-9.931***	-0.582	3.903**
	(39.948)	(1.419)	(16.426)	(5.181)	(6.449)	(3.415)	(1.808)	(1.594)
TechPro*MeatCons.	**95.657****	**2.882***	**31.221**	**11.378***	**12.418**	**9.701*****	**2.276**	**2.540**
	(42.557)	**(1.578)**	**(23.571)**	**(5.934)**	**(7.912)**	**(3.635)**	**(1.916)**	**(1.772)**
HigherDip*MeatCons.	**87.619***	**4.102*****	**58.424*****	**9.728***	**6.660**	**12.599*****	**3.129**	**3.743****
	(46.234)	**(1.569)**	**(20.463)**	**(5.825)**	**(6.645)**	**(4.187)**	**(1.934)**	**(1.762)**
Basal metabolic rate (Kcal/day)	0.571***							
	(0.119)							
Male (binary)	266.293***	1.919	61.714***	31.036***	26.028***	27.548***	13.387***	16.930***
	(67.744)	(1.174)	(23.326)	(6.204)	(6.103)	(3.583)	(2.087)	(1.853)
Aged 45-64 (binary)	-31.931	-10.147***	-123.657***	-11.084*	-36.538***	-10.276***	-2.506	1.122
	(47.233)	(1.167)	(23.052)	(5.818)	(6.712)	(3.416)	(1.965)	(1.680)
Daily smoking (binary)	-176.514***	3.068**	64.834	-17.422***	11.819*	-12.184***	-4.621**	-6.386***
	(34.801)	(1.464)	(42.215)	(5.423)	(6.556)	(3.109)	(1.778)	(1.338)
Alcohol consumption index (0-to-90 score)	-2.741*	-0.127***	-3.235***	-0.525***	0.085	-0.565***	0.052	-0.008
	(1.520)	(0.047)	(1.223)	(0.192)	(0.252)	(0.158)	(0.068)	(0.057)
Medium level of physical activity (binary)	120.764**	-3.458***	-22.112	3.689	-5.492	1.637	4.351**	4.502***
	(46.311)	(1.307)	(20.282)	(6.179)	(6.506)	(3.987)	(2.009)	(1.518)
High level of physical activity (binary)	254.661***	-4.229**	36.201	9.082	9.941	12.966**	8.022***	9.573***
	(65.612)	(1.778)	(39.712)	(8.916)	(10.285)	(6.166)	(2.791)	(2.254)
Medium level of sedentariness (binary)	-57.517	2.233	36.342	2.490	11.197	1.928	-2.640	-1.107
	(65.973)	(1.634)	(33.516)	(7.786)	(10.246)	(4.516)	(3.085)	(2.268)
High level of sedentariness (binary)	-93.023	2.128	48.887	-1.265	13.094	0.195	-1.897	-4.029
	(70.400)	(1.687)	(31.634)	(8.185)	(10.066)	(4.412)	(3.398)	(2.538)
Lunch at home (binary)	-19.073	-1.387	75.070**	-6.272	-5.803	2.798	0.245	-2.903*
	(46.111)	(1.149)	(31.499)	(6.039)	(5.993)	(4.626)	(1.920)	(1.606)
Declared as vegetarian (binary)	120.713	3.245	-20.766	1.821	-39.772**	-2.867	11.127***	4.894
	(93.955)	(6.050)	(50.339)	(15.596)	(17.204)	(8.019)	(4.221)	(3.633)
Number of adults per household	-8.654	-0.700	31.722**	-0.440	1.367	-2.509	-0.708	-0.244
	(23.674)	(0.716)	(14.254)	(3.290)	(4.568)	(1.801)	(1.150)	(1.019)
Number of children per household	-4.036	-1.228**	-33.862***	-0.127	2.435	-3.743**	-0.353	-0.149
	(23.382)	(0.579)	(9.694)	(2.279)	(3.536)	(1.455)	(0.779)	(0.821)
Season dummies	YES	YES	YES	YES	YES	YES	YES	YES
Urbanicity levels	YES	YES	YES	YES	YES	YES	YES	YES
Region dummies	YES	YES	YES	YES	YES	YES	YES	YES
Black's misreporting indexes	YES	YES	YES	YES	YES	YES	YES	YES
Constant	1,160.943***	40.773***	109.093	76.451***	75.062**	101.577***	64.941***	78.395***
	(261.854)	(5.070)	(124.777)	(19.205)	(28.813)	(12.167)	(7.531)	(8.771)
Observations	1,309	1,312	1,312	1,312	1,312	1,312	1,312	1,312
R-squared	0.535	0.210	0.173	0.241	0.176	0.334	0.401	0.560

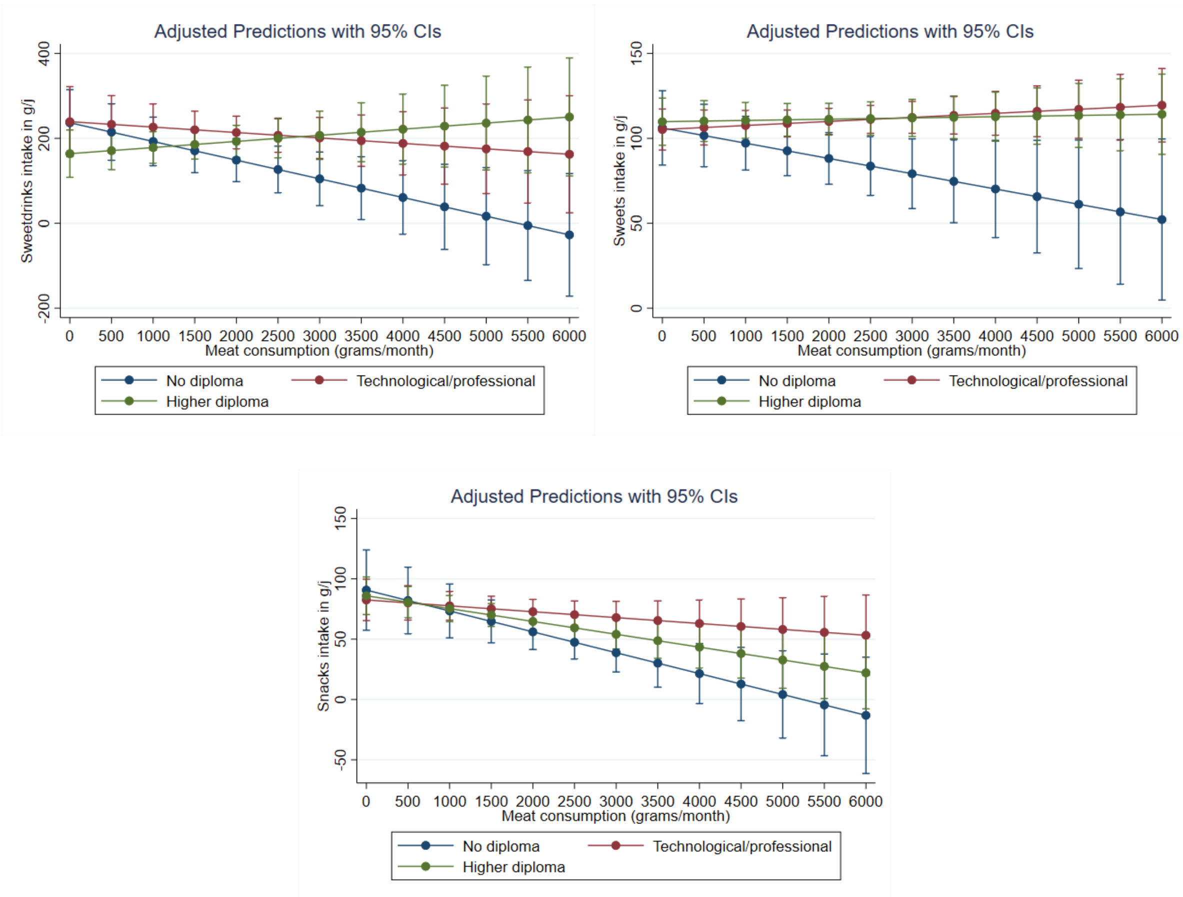
Notes: Estimates are weighted using the survey recommendations to guarantee the representativeness of the sample. Lactating and pregnant women were excluded as well as children (<18 yo) and the elderly (>65 yo). Standard errors are in parentheses. Levels of significance of fitted coefficients: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Source: INCA-3 (2014-2015).

Figure 3: Fitted diet indicators across education groups



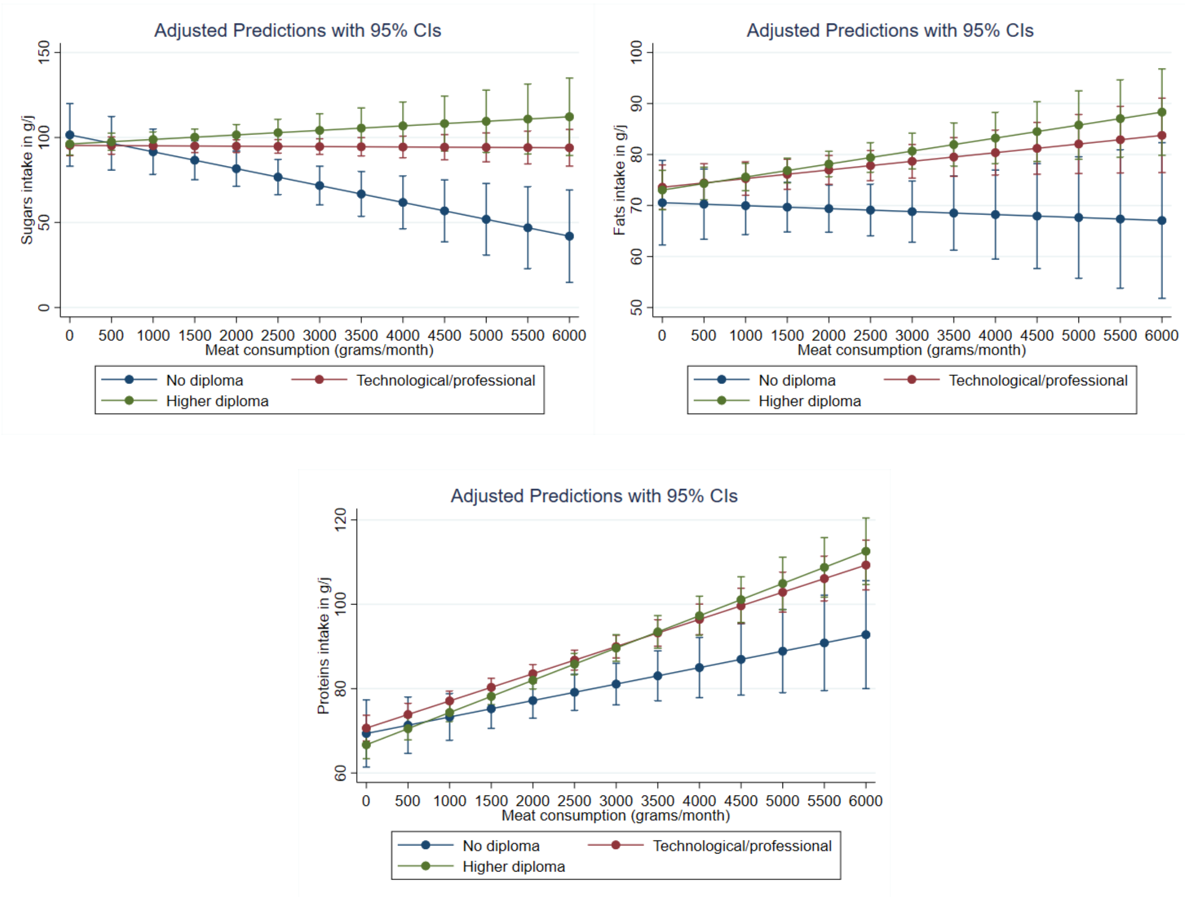
Notes: Estimates are weighted using the survey recommendations to guarantee the representativeness of the sample. Lactating and pregnant women were excluded as well as children (<18 yo) and the elderly (>65 yo). Estimates are adjusted by age, gender, smoking, alcohol consumption, physical activity, sedentariness, number of adults and children in the household, lunch place, vegetarian diet declaration, season of survey, urbanicity, region, and Black's index of under and overreporting. When total energy intake is used as dependent variable, we also control for the basal energy requirements of individuals. Confidence intervals (CIs) are fixed at the 95% level. Source: INCA-3 (2014-2015).

Figure 4: Fitted risky food intakes across education groups



Notes: Estimates are weighted using the survey recommendations to guarantee the representativeness of the sample. Lactating and pregnant women were excluded as well as children (<18 yo) and the elderly (>65 yo). Estimates are adjusted by age, gender, smoking, alcohol consumption, physical activity, sedentariness, number of adults and children in the household, lunch place, vegetarian diet declaration, season of survey, urbanicity, region, and Black's index of under and overreporting. Confidence intervals (CIs) are fixed at the 95% level. Source: INCA-3 (2014-2015).

Figure 5: Fitted macronutrient intakes across education groups



Notes: Estimates are weighted using the survey recommendations to guarantee the representativeness of the sample. Lactating and pregnant women were excluded as well as children (<18 yo) and the elderly (>65 yo). Estimates are adjusted by age, gender, smoking, alcohol consumption, physical activity, sedentariness, number of adults and children in the household, lunch place, vegetarian diet declaration, season of survey, urbanicity, region, and Black's index of under and overreporting. Confidence intervals (CIs) are fixed at the 95% level. Source: INCA-3 (2014-2015).

4. Discussion

Based on a representative sample of the French adult population, this study showed SES-specific trends regarding the association between meat consumption and several nutritional outcomes. While meat consumption is positively associated with BMI and overweight risk in upper SES groups, this relationship tends to be inversed in low SES groups. In other words, under-privileged individuals who eat less meat tend to have a higher BMI and a higher risk of being classified as overweight compared to their counterparts who eat more meat, but also compared to other socioeconomic groups. These results were robust to several measurements of SES, including education attainment, household income, occupation and an indicator of financial insecurity perception. To our knowledge, it is the first study to show opposite relationships between meat consumption and BMI between lower and higher socioeconomic groups.

Another important finding of the study is that associations between meat consumption and several indicators of diet quality may also depend on SES. For such outcomes, the difference across SES was especially noticeable when based on education groups. For the most educated adults, we consistently found that lower meat consumption was associated with lower UPF rate, as well as lower sweet drinks and sugar intakes. In the opposite, lower meat consumption among individuals without diploma was associated with a lower diet quality, which consistently may explain why lower meat consumption among lower social groups is positively correlated with BMI and overweight. Unhealthy plant-based foods such as sweets and highly processed foods are generally cheaper than healthy plant-based foods such as fresh fruit, legumes, and vegetables, or protein sources such as fish and dairy products that can replace meat (Vandevijvere et al., 2020). Hence, in a globalized context of abundance of affordable ultra-caloric and palatable food, it is not surprising that poorly educated individuals, with probably a low level of nutritional literacy, are more likely to have poor-fiber energy-dense diets when they consume less meat. By contrast, higher SES individuals might be more successful at composing healthier diets than low SES individuals in a context of lower meat consumption.

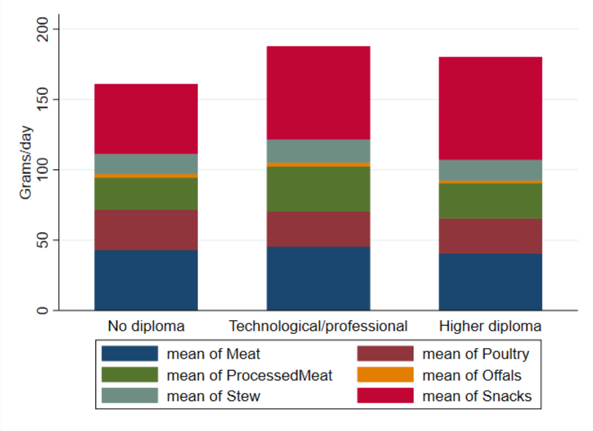
Finally, our results echo the literature on the 'protein leverage' hypothesis as determinant of the obesity epidemic. Specifically, we contribute to enrich the notion of protein paradox that opposes traditional societies where low-protein diets were associated to health and longevity because of the quasi-unique availability of healthy meat-substitutes (fruits, vegetables, legumes, and starch), versus modern industrialized food environments where a slight protein reduction in diet may increase appetite and energy intake, especially through UPF intakes (Simpson and Raubenheimer, 2005; Steele et al., 2018). Through our application on the French population, we showed that such a protein paradox might also appear in modern societies given a strong heterogeneity in food environments and preferences, both factors being highly correlated to individual SES. Indeed, in high-income countries like France, low-SES populations disproportionally live in obesogenic area where UPF are highly promoted and fresh food less accessible (Coutinho et al., 2023; Giskes et al., 2011). Further, individuals living in poverty contexts tend to prefer to maximize their present satisfaction by consuming high-fat high-sugar food and beverage perceived as palatable (qualified as "short-term low-risk strategies") rather than invest in a future and uncertain health-based satisfaction through suitable food intake restrictions and regular physical exercise (qualified as "long-term high-risk strategies") (Levine, 2015). Hence, in a speculative context of meat scarcity leading to (slightly) reduce total protein intakes in diet, low-SES individuals may react differently compared to more privileged individuals. While the latter might be more willing to invest in their health by choosing appropriate meat-substitutes, the former might offset a decrease in meat-based protein by an increase in UPF and sugar intakes, leading to a calorie surplus and an increase of BMI.

Conclusion

Given the important, and growing, inequalities in high-income countries, special attention needs to be paid to diet changes that could impact health and nutrition. Dietary transition towards a more sustainable diet is one such change. While many studies have shown an association between reducing meat consumption and weight loss, our analysis nuances these results by showing that diets lower in meat are associated with a lower BMI only in individuals with a higher SES. To an even greater extent, the relationship tended to be inversed for low-SES individuals. However, given the cross-sectional nature of our study, we cannot conclude that a reduction in meat intakes causally leads to changes in diet according to SES. Based on our results, there is clearly a need to identify causal nutritional effects of dietary changes in populations with different SES in order to understand whether promoting a reduction in meat consumption could widen disparities in weight status, as well as in broader health outcomes. Experiments or observational studies using longitudinal data combined with endogeneity-correction tools (e.g., instrumental variables strategy) should be implemented to confirm these SES-specific effects.

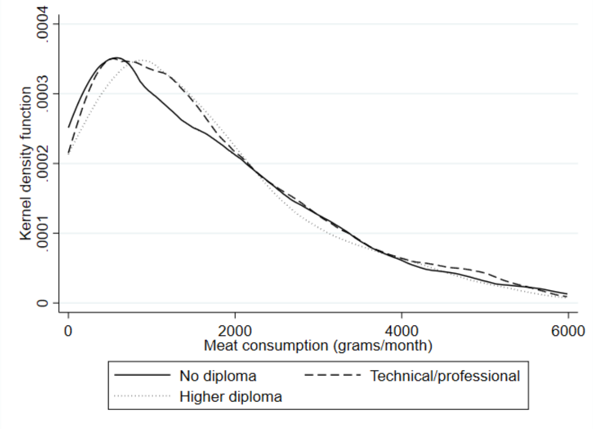
ONLINE SUPPLEMENTARY MATERIALS

Figure S1: Types of meat according to education groups



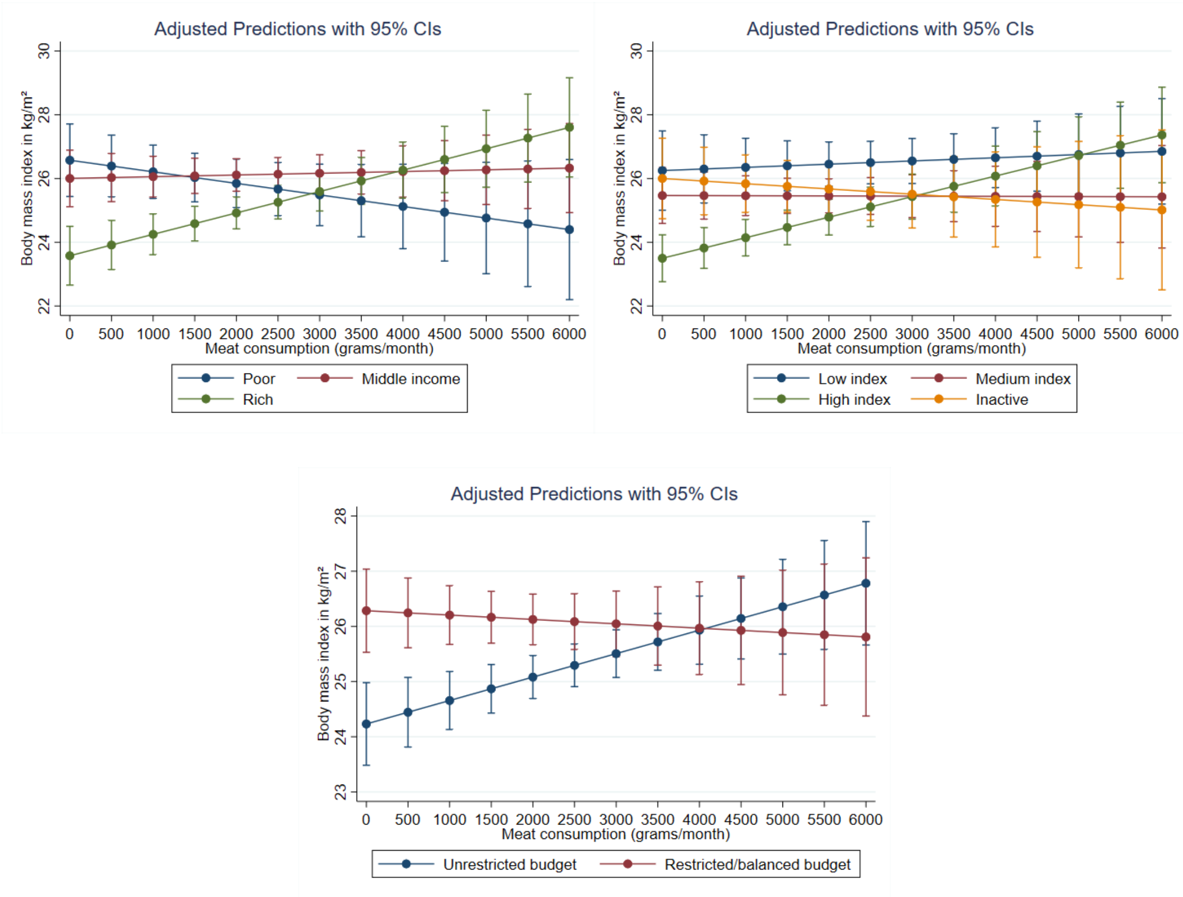
Notes: Lactating and pregnant women were excluded as well as children (<18 yo) and the elderly (>65 yo).
Source: INCA-3 (2014-2015).

Figure S2: Distribution of meat consumption across education groups



Notes: Lactating and pregnant women were excluded as well as children (<18 yo) and the elderly (>65 yo).
Source: INCA-3 (2014-2015).

Figure S3: Adjusted regressions of BMI on meat consumption by household income groups, occupation groups, and economic insecurity perception



Notes: Estimates are weighted using the survey recommendations to guarantee the representativeness of the sample. Lactating and pregnant women were excluded as well as children (<18 yo) and the elderly (>65 yo). Estimates are adjusted by age, gender, smoking, alcohol consumption, physical activity, sedentariness, number of adults and children in the household, lunch place, vegetarian diet declaration, season of survey, urbanicity, region, and Black's index of under and overreporting. Confidence intervals (CIs) are fixed at the 95% level. Source: INCA-3 (2014-2015).

Table S1: Regression of all dependent variables on discrete education index, meat consumption and covariates

	BMI (kg/m²)	Energy intake (Kcal/day)	UPF intake (% total energy intake)	Sweetdrinks intake (g/day)	Sweets intake (g/day)	Snacks intake (g/day)	Sugar intake (g/day)	Fat intake (g/day)	Protein intake (g/day)
Meat consumption (kg/month)	-0.909*	-12.452	-3.471**	-80.317***	-5.585	-8.678	-11.216***	-1.062	3.662**
	(0.470)	(41.864)	(1.406)	(27.754)	(5.370)	(7.295)	(3.648)	(2.022)	(1.650)
Diploma level (discrete)	-0.600***	3.127	-1.206***	-19.012***	-0.019	-0.181	-1.002	0.206	-0.529
	(0.123)	(11.425)	(0.375)	(5.644)	(1.582)	(2.106)	(1.194)	(0.487)	(0.493)
DiplomaLevel*MeatCons.	**0.132***	**7.288**	**0.423****	**9.343****	**0.753**	**-0.002**	**1.385****	**0.360**	**0.379***
	(0.051)	**(5.230)**	**(0.158)**	**(3.016)**	**(0.644)**	**(0.814)**	**(0.472)**	**(0.231)**	**(0.206)**
Basal metabolic rate (Kcal/day)		0.553***							
		(0.118)							
Male (binary)	0.203	273.758***	2.038*	63.224***	31.244***	26.678***	27.442***	13.433***	17.057***
	(0.361)	(67.836)	(1.170)	(23.089)	(6.186)	(6.189)	(3.537)	(2.075)	(1.864)
Aged 45-64 (binary)	1.693***	-45.353	-10.508***	-130.243***	-12.633**	-37.469***	-11.226***	-2.825	0.695
	(0.357)	(48.676)	(1.248)	(23.138)	(5.882)	(6.660)	(3.519)	(1.992)	(1.711)
Daily smoking (binary)	-0.585*	-174.212***	3.016**	63.956	-17.181***	12.484*	-12.239***	-4.418**	-6.272***
	(0.349)	(34.689)	(1.501)	(42.132)	(5.396)	(6.549)	(3.128)	(1.788)	(1.359)
Alcohol consumption index (0-to-90 score)	0.010	-2.597*	-0.122**	-3.227***	-0.503**	0.101	-0.554***	0.047	-0.008
	(0.012)	(1.533)	(0.048)	(1.236)	(0.194)	(0.254)	(0.157)	(0.068)	(0.058)
Medium level of physical activity (binary)	-1.025***	128.390***	-3.046**	-15.997	4.843	-3.665	1.844	4.615**	4.979***
	(0.368)	(47.968)	(1.324)	(20.950)	(6.069)	(6.426)	(4.059)	(1.998)	(1.563)
High level of physical activity (binary)	-1.551***	254.689***	-4.048**	37.087	9.191	9.476	13.575**	7.921***	9.579***
	(0.488)	(65.372)	(1.779)	(40.400)	(8.881)	(10.404)	(6.256)	(2.753)	(2.254)
Medium level of sedentariness (binary)	-0.356	-57.760	2.201	35.716	2.456	11.400	1.717	-2.505	-0.994
	(0.550)	(66.712)	(1.637)	(33.960)	(7.798)	(10.096)	(4.490)	(3.116)	(2.291)
High level of sedentariness (binary)	0.746	-88.800	2.041	46.857	-0.921	13.352	0.491	-1.792	-4.043
	(0.518)	(71.272)	(1.683)	(31.547)	(8.269)	(9.917)	(4.404)	(3.421)	(2.563)
Lunch at home (binary)	0.157	-27.106	-1.690	71.768**	-7.389	-7.007	2.172	0.178	-3.108*
	(0.321)	(47.061)	(1.167)	(30.851)	(6.022)	(6.099)	(4.656)	(1.927)	(1.645)
Declared as vegetarian (binary)	0.319	128.287	3.395	-11.574	2.823	-38.430**	-2.561	11.500***	5.157
	(1.088)	(87.165)	(6.199)	(48.006)	(15.541)	(15.899)	(7.625)	(4.264)	(3.862)
Number of adults per household	0.418*	-10.743	-0.772	32.769**	-0.817	0.600	-2.594	-0.591	-0.195
	(0.236)	(23.438)	(0.725)	(15.237)	(3.281)	(4.491)	(1.824)	(1.115)	(1.009)
Number of children per household	-0.024	-5.320	-1.212**	-33.326***	-0.250	2.279	-3.850***	-0.428	-0.181
	(0.158)	(23.848)	(0.563)	(9.510)	(2.369)	(3.510)	(1.458)	(0.781)	(0.821)
Season dummies	YES	YES	YES	YES	YES	YES	YES	YES	YES
Urbanicity levels	YES	YES	YES	YES	YES	YES	YES	YES	YES
Region dummies	YES	YES	YES	YES	YES	YES	YES	YES	YES
Black's misreporting indexes	YES	YES	YES	YES	YES	YES	YES	YES	YES
Constant	28.803***	1,202.091***	46.191***	236.588**	80.602***	74.067**	105.809***	65.950***	82.414***
	(1.600)	(273.884)	(5.104)	(113.399)	(19.983)	(31.437)	(13.005)	(7.696)	(9.459)
Observations	1,309	1,309	1,312	1,312	1,312	1,312	1,312	1,312	1,312
R-squared	0.230	0.530	0.206	0.173	0.236	0.170	0.328	0.399	0.555

Notes: Estimates are weighted using the survey recommendations to guarantee the representativeness of the sample. Lactating and pregnant women were excluded as well as children (<18 yo) and the elderly (>65 yo). Standard errors are in parentheses. Levels of significance of fitted coefficients: *** p < 0.01, ** p < 0.05, * p < 0.1. Source: INCA-3 (2014-2015