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Taxing Highly Processed Foods: Impacts on Obesity and Underweight in Sub-Saharan Africa*

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Abstract

The consumption of highly processed food has been singled out as one of the factors responsible for the rapidly increasing prevalence of obesity and its associated non-communicable diseases and costs. While obesity prevalence is still comparatively low in lower-income sub-Saharan Africa (SSA), development prospects in this region render its markets especially interesting for these foods, whose consumption is already growing at higher rates than in developed countries. This might be reflected in the massive rise in obesity prevalence growth rates in SSA over the past decade, which has occurred while many of these countries are simultaneously struggling with high undernutrition prevalence.

With a focus on SSA, this study econometrically investigates the effect of higher import tariffs on highly processed *vis-à-vis* less-processed foods with respect to their impacts on obesity and underweight prevalence, utilizing a newly constructed cross-country panel dataset. The effects of the tariff differences are found to be significant and substantial in cases differentiated by income level of the country as well as by gender. The results more generally show that policies affecting the consumer price differential between the two food groups are effective for influencing obesity and underweight prevalence and that these two issues cannot be treated separately.

Keywords: highly processed foods; obesity; underweight; food policies; taxes; Sub-Saharan Africa.

1 Introduction

The rapid growth in prevalence of obesity has long been recognized as a serious global problem and has even been called an epidemic (WHO, 2003; IFPRI, 2016; Townsend et al., 2016). Paradoxically, this problem is not exclusive to the developed world but also prevalent in developing countries, which are simultaneously challenged by persistent problems of undernutrition. In 2013, the share of adults considered overweight

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worldwide grew to 36.9 percent for men and 38.0 percent for women, with developing countries accounting for 60 percent of global obesity prevalence (Ng et al., 2014). Overweight (body mass index [BMI] of 25-30 kg/m^2), and particularly obesity (BMI > 30 kg/m^2), is associated with reduced overall health, loss of productivity and the development of an array of non-communicable diseases (NCDs) such as diabetes, cardiovascular diseases and cancer, and correspondingly with substantial health and economic costs[1].

Obesity prevalence rises with economic development; obesity is mainly the result of a continued excess of energy intake over expenditure. As countries develop economically, not only are incomes rising – allowing the consumption of more calories while expending less physical energy – but also diets are shifting from staple foods towards, for example, more animal products, fats and sugar, as well as more highly processed and convenience foods (Kearney, 2010). This culminates in the developed-country or "Western" diet, which is characterized by higher intake of added sugars, refined carbohydrates and animal-source foods and fats and is nutritionally imbalanced, as consumers tend to ingest excess calories and insufficient levels of micronutrients. This shift in diet is seen as one of the primary nutrition-related causes of obesity (see, e.g. Popkin and Gordon-Larsen, 2004) and dietary patterns in developing countries are indeed becoming increasingly similar to the Western diet (Popkin et al., 2012) with an accompanying rise in obesity prevalence.

An important role in the emergence of nutrient imbalance and thus of the obesity epidemic is attributed to the shift in consumption towards highly processed foods[2] (see, e.g. Hawkes, 2005; Moubarac et al., 2013; Popkin et al., 2012), which are often energy-dense but micronutrient-poor. These foods are nevertheless highly popular with consumers due to a multitude of (perceived) positive attributes, such as short or no preparation time, high palatability, ease of storage and transport, long shelf-life, lower price relative to less processed foods, improved food safety, or low cost per calorie. Consequently, although highly processed foods are part of the cause for the obesity problem, they might be part of a solution for the undernutrition problem (Augustin et al., 2016).

Highly processed foods are very profitable (Monteiro et al., 2013; Stuckler et al., 2012) but their markets in developed countries are largely saturated (Reardon et al., 2003). By contrast, countries in sub-Saharan Africa (SSA) continue to develop rapidly and promise strong growth in consumption and higher profits. Hence, multinational food companies are increasingly targeting SSA markets and intensifying their marketing efforts. Continued trade and investment liberalization create an environment conducive for foreign direct investment (FDI) and exploitation of global supply chain logistics which facilitate the expansion of supermarket chains, thereby increasing the availability and lowering the prices of highly processed foods (Reardon et al., 2003).

Indeed, Stuckler et al. (2012) observed that multinational food companies have already penetrated middle-income markets to a similar extent as they have markets in high-income countries. Using survey data from towns in Central Kenya, Demmler et al.

[1]Recent literature reviews on economic costs of obesity are provided by Cawley (2015); Hoque et al. (2016); Specchia et al. (2015); Tremmel et al. (2017).

[2]Note that the term "highly processed food" here describes food processed intensively in a number of steps but at the same time implies specific properties of the formulation involving multiple ingredients, as detailed in Section 2.

(2018) found that individuals shopping in supermarkets are consuming larger shares of dietary energy from highly processed foods than individuals who do not. According to Moodie et al. (2013) and Stuckler et al. (2012), consumption of highly processed foods is, in fact, already growing at much higher rates in low- and middle-income than in high-income countries. Studying four SSA countries, Holmes et al. (2018) found evidence that a diet containing a high consumption level of processed food is associated with a multiple times higher risk of being overweight or obese than consumption at a low level.

Furthermore, undernutrition is still a widespread problem in SSA and it is known that *in utero* and childhood undernutrition increases susceptibility to obesity in later life (Popkin et al., 2012; Nettle et al., 2017). In its entirety, this constellation of factors in SSA could imply that with progressing economic development the obesity problem might become even more severe for current and future generations in SSA than what has been observed in developed countries until now.

Consequently, policies to discourage the consumption of highly processed foods to counteract the rise of obesity might have more value the sooner they are implemented, and they need to be integrated with the policies to combat undernutrition.

In efforts to reduce obesity prevalence and associated NCDs, developed and developing countries alike have been experimenting with an array of measures to counter the epidemic through channels such as education and information (e.g. food labelling, nutrition education, dietary guidelines, school physical activity programmes), price incentives (food or food content taxes and subsidies) and regulation (marketing targeted at young people, food re-formulation, school food); see Alston et al. (2016) or Hyseni et al. (2017) for recent overviews.

Many countries have adopted or are considering consumption taxes or subsidies on specific food groups or contents to discourage unhealthy eating or encourage healthy eating, as reviewed in Thow et al. (2018). A frequently tax-targeted food group is sugary drinks (soft drinks). This is a narrow, well-defined group, believed to substantially contribute to the obesity problem, and the effects of corresponding taxes have been the subject of many research studies; see Cornelsen and Smith (2018) for an overview. Taxes on other specific food groups such as sugar or fat have been less widely studied.

However, the consumption of highly processed foods in general is suspected to promote obesity – see, for example, Hawkes (2005), Thow et al. (2010), Monteiro et al. (2013) and Moubarac et al. (2013) – but corresponding taxes have received little attention, likely due to the lack of suitable data. Moreover, the concurrent prevalence in SSA of both obesity and undernutrition – the double burden of malnutrition – strongly complicates the problem faced by policy-makers, as it is often the case that policies applied to decrease undernutrition increase the obesity problem and vice versa. Hence, policy-makers need to pay attention simultaneously to the potential effects on obesity and on undernutrition prevalence when considering food tax or subsidy policies for SSA.

The present study expands this literature and investigates the potential of taxes and subsidies on highly processed foods as a means for reducing obesity prevalence, with a particular focus on SSA. The questions being investigated include: To what extent would it be possible to reduce obesity and underweight prevalence through taxes or subsidies that increase the price gap between unhealthy highly processed foods and healthy foods? What effects might further trade liberalization have on those prevalence rates? How big would such policy interventions need to be to have a notable impact? Under what conditions and for which population groups would these tax policies be effective?

In contrast to most other studies looking at the effects of taxing specific food groups on obesity using national survey data for individual countries, here we take a global perspective and – to the best of our knowledge – present the first study examining policies on highly processed foods in general. As no consistent database for prices and taxes on the global level is available, we create a novel concordance between a classification system of foods and one of traded goods to facilitate the exploitation of data from an import tariff database which has been regularly and consistently updated and which now covers most countries of the world over a long time period.

Many countries employ import protection strategies, which cause differences in tariffs across products and according to level of processing of the products – for example, tariff escalation. Assuming pass-through of taxes applied at the national border to retail prices, such a tariff pattern results in policy-created price differences between unprocessed, basic foods and their processed counterparts, which discourages consumption of the latter and may thereby lower obesity prevalence. However, if processed foods are an important source of cheap calories for the poorer population, this pattern may increase underweight prevalence at the same time.

The results from a global econometric analysis are then used to assess the potential of tax policies on highly processed foods to affect obesity and underweight prevalence. On the one hand, such interventions are particularly problematic in SSA countries because of the simultaneous occurrence of over- and underweight prevalence but, on the other hand, such policies are also potentially more effective there due to the higher responsiveness of low-income consumers for whom obesity prevalence is predicted to grow fastest (see Ziraba et al., 2009; Jones-Smith et al., 2012).

The remainder of the study is organized as follows. Section 2 introduces the data employed and the econometric approach. Section 3 then presents and discusses the econometric estimations and their results. Finally, Section 4 synthesizes the outcomes and draws policy conclusions.

2 Methodology and Data

For this study we take an indirect approach to investigate the potential of tax policies to affect obesity related to processed food consumption. The reason for this approach is that availability of country-level data on consumption, consumer prices and consumption taxes is insufficient and frequently lacks the detail required to distinguish processed from unprocessed food items. Therefore, our strategy to empirically investigate this question is based on the fact that countries systematically differentiate their import tariff patterns between processed and unprocessed food products. We assume that import tariffs transfer directly to the retail prices of both the imported products and their domestically produced counterparts. Hence, such tariffs create a price wedge between processed and unprocessed products, which discourages the consumption of processed *vis-à-vis* unprocessed foods and thereby affects obesity and underweight prevalence.

2.1 Food classification and data

The approach chosen has the advantage that data on import tariffs have been systematically collected by the WTO and previously the GATT since 1988 from all member countries. These data are available from the UNCTAD Trade Analysis Information System database (TRAINS, 2017) and cover the large majority of countries for the recent years. The data are classified according to the Harmonized Commodity Description and Coding System (HS) at the 6-digit level, which differentiates 1 300 agricultural and food products by various criteria, including the degree to which they have been processed.

Nevertheless, the HS classification has been designed for customs purposes so that here the HS food items need to be reclassified with respect to their obesity-related properties, i.e. according to their degree of processing and ingredient composition. The reason for the scarcity of data on processed foods consumption is partly found in the traditional focus of research on identifying the health effects of foods classified into groups based on either their botanical and animal species origin or their nutrient content, whereas no comprehensive classification of different food processing activities and their effects on foods and health is available yet (Fardet et al., 2015). However, five systems which classify foods according to processing have been used for health studies (Moubarac et al., 2014).

Of those five systems, here we adopt the rather recent NOVA classification system (Monteiro et al., 2016), which has previously been applied successfully, for example, in a study by Canella et al. (2014) to identify the association between consumption of ultra-processed foods and obesity in Brazil. The NOVA system classifies food into the following four groups: (NOVA 1) unprocessed or minimally processed foods, such as fresh or frozen fruits and vegetables; (NOVA 2) processed culinary ingredients – for instance, starches or syrups; (NOVA 3) processed foods which often have been processed to increase their durability and are usually recognizable as the original food – for example, canned vegetables, tinned fish preserved in oil, salted nuts or cheese; and finally (NOVA 4) ultra-processed food and drink products. The latter might be described as foods engineered by recombining ingredients created through extraction from and refinement of food and other organic sources through physical, biological and chemical processes. They typically contain more than five ingredients. Examples are carbonated soft drinks, crisps and other sweet, fatty or salty snack foods. The differentiating quality of NOVA 4 relative to NOVA 3 processed food products is that the former incorporate substances that have previously been extracted. Some typical processing techniques applied to ultra-processed foods include extrusion, moulding and pre-processing. When products would fit into the NOVA groups 1 to 3 but contain "cosmetic or sensory intensifying additives" – e.g. artificial sweeteners – then they are also classified as NOVA 4.

It is worth noting that a classification according to the level of processing of food, such as the NOVA classification, is a crude proxy for grouping products with particular unhealthy properties (see Gibney et al., 2017, for a critique on the NOVA classification.) Botelho et al. (2016) argue that it is not the number of steps or the intensity of processing but the list of ingredients which renders a food unhealthy. Fardet et al. (2015) add that certain processing operations can change the structure of food and thereby alter its nutritional and health potential.

The final reclassification maps 897 6-digit HS tariff lines, corresponding to all agricultural and food items suitable for human consumption, to the four NOVA categories. This reclassification is applied to calculate a trade value-weighted import tariff average for each NOVA category and each country and year pair available in the TRAINS database. More specifically, the import values from the world into each country as well as the corresponding "weighted average" of the "effectively applied tariff" rate at the HS 6-digit level are utilized.

Since TRAINS reports the trade for the EU as a whole rather than of its member countries separately, we separate the EU import data into individual member countries using the UN COMTRADE (2017) database: for each member country and HS product code, we combine the EU's common external tariff as reported in the TRAINS database with the individual country's import value data from the COMTRADE database. In this way, we were able to recover valuable data for the diverse EU member countries.

Our main hypothesis is that the difference in prices between highly processed and less-processed products influences food consumption behaviour and thus related obesity prevalence. Hence, we calculate our main explanatory variable as the difference in the aggregate average trade-weighted tariff between the NOVA 4 and the NOVA 1 to 3 categories for each country and year.

The variable to be explained in our study is obesity prevalence measured as the percentage of the adult population aged 18 and above with a BMI equal to or greater than 30 kg/m^2. The percentage of underweight prevalence, similarly defined by a BMI equal to or less than 18.5 kg/m^2, is the second dependent variable adopted to examine the effects on the undernourished population.

This obesity and underweight data is taken from a study recently published in *The Lancet* by the NCD Risk Factor Collaboration (NCD-RisC, 2016). In a large-scale effort, NCD-RisC collected 1 698 population-based measurement studies and utilized those to estimate a complete and methodologically consistent large dataset covering 200 countries over the period from 1975 to 2014, using a Bayesian estimation approach. The BMI, obesity and underweight data provided by NCD-RisC were age-standardized to a World Health Organization (WHO)-defined standard population to allow age structure-independent comparability across countries. In the estimation, the authors also correct for the many differences between datasets, such as self-reported versus measured heights and weights, yielding a dataset comparable across countries. The female- and male-specific percentages taken from this dataset are combined into single values by using the share of females in the total population, as provided in the World Bank's World Development Indicators (WDI) database (WDI, 2017). Note that, while BMI has emerged as a widely used standard to measure obesity and underweight because of the ease of obtaining the information for its calculation, it is not perfect as it does not differentiate, for example, between weight from fat or muscle, or among body shapes or genders.

A multitude of factors influence obesity prevalence. In order to derive a sound causal relationship between the NOVA-categorized import tariff measures and obesity prevalence, we control for factors which influence obesity and are potentially correlated with those tariff measures. The first of these is income per capita, proxied by GDP per capita in our study, as typically price elasticities of food demand change with the level of income, where higher incomes are accompanied with lower responsiveness to price changes. In addition, we add main drivers of obesity to improve the precision of the estimates. These include the percentage of the population living in urban areas, percentage of females working, percentage of the population aged 65 and above, and trade as a share of GDP; these have all been taken from the WDI database (WDI, 2017). Indicators for information flows and cultural proximity have been retrieved from the KOF Index of Globalization[3] (KOF, 2017), and the international Food Price Index (FPI) from the Food and Agriculture Organization of the United Nations (FAO) (FAO, 2017). The final variable is the percentage of the value of global NOVA 4 imports in total NOVA 1 to 4 imports. The choice of variables has been guided by theoretical considerations but also by data availability.

In order to construct a balanced panel covering as many countries as possible, the period from 2007 to 2013 has been chosen. In total, the final dataset represents 101 countries with complete data for all variables, as detailed in Table 1. The countries have been categorized by income group according to the World Bank's classification[4] and additionally cross-categorized by SSA or non-SSA country. The bottleneck is the availability of the trade data, which has been improving over time. Variable descriptions and summary statistics are provided in Table 2.

2.2 Econometric specification

Our analysis employs a panel fixed effects estimation approach, as presented in the generally formulated equation (1).

$$Y_{it} = \tau T_{it-1} + \sum_{g=1}^{G} \gamma_g (T_{it-1} \times D_{ig}) + \sum_{j=1}^{J} \beta_j X_{jit-1} + \sum_{k=1}^{K} \gamma_k Z_{kt-1} + \alpha_i + \epsilon_{it} \quad (1)$$

In our base specification, Y_{it} represents obesity (or underweight) prevalence of country i in year t. T_{it} denotes our main variable of interest, the difference in tariffs between NOVA 4 and NOVA 1 to 3 ($\text{dTariff}_{\text{N4-N123}}$). T_{it} is interacted with the dummy variable D_{ig} which is one if country i belongs to the country income group g (as specified in Table 1) and zero otherwise.

X_{jit} includes the set of J additional control variables which vary over countries and time. Z_{kt} is a set of K explanatory variables which control for global developments over time. α_i accounts for all country-specific fixed effects which are time-constant – in particular, geographic, institutional and cultural characteristics. Finally, ϵ_{it} is the error term.

More specifically, X_{jit} comprises the ln(GDP per capita) and ln(GDP per capita)^2 to model the non-linear relationship between obesity and per capita income levels as one of the most important determinants of obesity. The percentage of urban population is included to account for better access to and availability of NOVA 4 foods in urban areas

[3]See Dreher (2006) for detailed descriptions of these indices.

[4]The World Bank list of economics June 2017, retrieved 29 October 2017 from https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups.

Table 1: Countries included in the analysis, by income group.

Income group	Region	n	Countries
Low income (LI)	Non-SSA	2	Haiti, Nepal
	SSA	13	Benin, Burkina Faso, Burundi, Central African Republic, Gambia, Guinea-Bissau, Madagascar, Mali, Niger, Senegal, Togo, Uganda, United Republic of Tanzania
Lower middle income (LMI)	Non-SSA	17	Armenia, Bangladesh, Bolivia (Plurinational State of), Egypt, El Salvador, Georgia, Guatemala, Honduras, India, Indonesia, Jordan, Kyrgyzstan, Nicaragua, Pakistan, Philippines, Republic of Moldova, Ukraine
	SSA	5	Cabo Verde, Cameroon, Côte d'Ivoire, Kenya, Zambia
Upper middle income (UMI)	Non-SSA	19	Albania, Argentina, Belize, Bosnia and Herzegovina, Brazil, Bulgaria, Colombia, Costa Rica, Croatia, Cuba, Fiji, Guyana, Malaysia, Mexico, Panama, Paraguay, Russian Federation, The former Yugoslav Republic of Macedonia, Venezuela (Bolivarian Republic of)
	SSA	5	Botswana, Gabon, Mauritius, Namibia, South Africa
High income (HI)	Non-SSA	40	Australia, Austria, Bahrain, Belgium, Canada, Chile, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Kuwait, Latvia, Lithuania, Luxembourg, Malta, Netherlands, New Zealand, Norway, Poland, Portugal, Qatar, Republic of Korea, Singapore, Slovakia, Slovenia, Spain, Sweden, Switzerland, United Kingdom, United States of America, Uruguay

Source: Own elaboration.

due to the density of shops and supermarkets and better transportation infrastructure. The share of the female population participating in the labour force is added to pick up effects arising from increased opportunity costs of working women and accounts for the reduced time required for meal preparation as a result of increased consumption of pre-prepared NOVA 4 foods. Furthermore, the share of the population age 65 and above indicates a population group which is associated with lower metabolic rates and lower levels of physical activity. Trade as a percentage of GDP is a proxy for trade openness, which increases availability and decreases prices of foods. Increased market access for multinational food companies could potentially result in lower prices for NOVA 4 relative to NOVA 1 to 3 products. The information flows index is composed of measures for Internet, television and newspaper use and thus represents a measure of marketing and international cultural exposure which might affect consumption preferences. The cultural proximity index is constructed from data on penetration of McDonald's restaurants and IKEA stores as well as trade in books, and is supposed to measure the level of cultural convergence which might indicate preferences for "Western"-culture products. The latter two indices could also indicate the level of infrastructure development and liberalism of policies and thus might also be correlated with the penetration of supermarkets and foreign food companies, which in turn could potentially lead to increased access to and reduced prices of NOVA 4 *vis-à-vis* NOVA 1 to 3 foods.

Table 2: Descriptive statistics.

Variable	Description	All			
		Mean	SD	Min	Max
% obese	Obese population (% of total)	16.6	8.2	1.9	36.7
	Underweight population (% of total)				
$\text{dTariff}_{\text{N4-N123}}$	NOVA 4 minus NOVA 1 to 3 import tariff	0.1	16.3	-109.9	186.9
$\text{dTariff}_{\text{N34-N12}}$	NOVA 3 and 4 minus NOVA 1 and 2 import tariff	-0.6	13.8	-126.3	105.4
$\text{Tariff}_{\text{N123}}$	NOVA 1 to 3 import tariff	12.1	13.6	0.0	145.9
$\text{Tariff}_{\text{N4}}$	NOVA 4 import tariff	12.2	14.0	0.0	188.6
$\text{Tariff}_{\text{N12}}$	NOVA 1 to 2 import tariff	12.3	14.5	0.0	157.1
$\text{Tariff}_{\text{N34}}$	NOVA 3 to 4 import tariff	11.7	9.8	0.0	106.8
GDP/capita	GDP per capita (constant 2010 US$) / 1000	17.5	21.7	0.2	112.0
% urban	Urban population (% of total)	62.3	21.8	9.9	100.0
% female labour participation	% of females labour participation	52.8	12.8	14.0	87.8
% trade/GDP	Trade (% of GDP)	91.7	57.1	22.1	441.6
% age $\geq$ 65	Population ages 65 and above (% of total)	9.5	6.0	1.1	25.0
Information flows	Information flows index (KOF)	71.1	18.5	30.5	98.1
Cultural proximity	Cultural proximity index (KOF)	44.4	34.1	1.0	97.1
FPI	Global real food price index (FAO)	194.9	24.5	160.3	229.9
Global % $\text{imports}_{\text{N4}}$	Global NOVA 4 imports (% of total NOVA imports)	21.9	0.8	20.9	23.2

Source: Own computation.

Z_{kt} comprises FAO's international FPI and the share of the global value of NOVA 4 imports in total global NOVA 1 to 4 imports. The FPI is an index composed of international prices for 23 food commodities and has been deflated using a manufactures unit value index (FAO, 2013). Correspondingly, the FPI is a proxy measure for the global development of basic NOVA 1 food prices relative to prices of manufactured products such as NOVA 4 foods. Although NOVA 1 to 3 products are also inputs to the production of NOVA 4 foods, they likely represent only a small share of NOVA 4 production costs compared with manufacturing costs. Thus, an increase in the FPI tentatively indicates that global NOVA 1 prices rise relative to those of NOVA 4 and thus affect the price gap. Finally, the share of the global value of NOVA 4 imports in total global NOVA 1 to 4 imports is taken as an indication of the general state of competitiveness of NOVA 4 products compared with NOVA 1 to 3 products. This includes, among other factors, the technological progress in the design, production and distribution of NOVA 4 products over time, which alter consumer preferences.

Other variables have been excluded because their coefficients turned out not to be statistically significant, at least at the 10 percent level – e.g. measures of foreign direct investment – or because their data availability was insufficient – e.g. measures related to education level or physical activity.

Note that all independent variables have been lagged by one year in order to allow time for the drivers to operate and their effects to appear in the respective prevalence rate.

The Lagrange multiplier test for the presence of fixed effects by Honda (Baltagi, 2005), confirmed the presence of country-fixed effects (null hypothesis rejected) but absence of time-fixed effects (null hypothesis not rejected) from the baseline regression. Contrasting random versus fixed effects assumptions, using the Hausman test (Baltagi, 2005), rejects the null hypothesis that the random effects model is consistent. Thus, we continue with a country-fixed effects model estimated using ordinary least squares regression. All standard errors reported are heteroskedasticity- and serial correlation-consistent, calculated according to Arellano; see, for instance, Baltagi (2005).

3 Results and Discussion

Table 3 presents the regression results for the main analysis of the impacts of the NOVA 4 to NOVA 1 to 3 tariff difference (henceforth called dTariff) on obesity and underweight, respectively. The base specification with percentage of obesity as the independent variable is presented in column (1) alongside two robustness checks in columns (2) and (3). The base specification for the percentage of underweight is shown in column (4). Starting with column (1), most estimated coefficients are statistically different from zero at the 5 percent significance level and have the expected sign. In most cases, they are also in line with the findings from the sparse literature which, similarly to this study, utilizes regression analysis of cross-country data for estimating the effects of determinants of obesity prevalence (Goryakin, Rocco and Suhrcke, 2017; Loureiro and Nayga, 2005) but with different foci and different datasets and countries. Moreover, here we also include such literature focusing on BMI (Goryakin, Monsivais and Suhrcke, 2017; Lawson et al., 2016; Ljungvall, 2013; de Vogli, Kouvonen, Elovainio and Marmot, 2014; de Vogli, Kouvonen and Gimeno, 2014). Although an increase in population average BMI is neither a necessary nor a sufficient condition for an increase in obesity prevalence, in most cases the two indices are likely to be moving together.

The effect of GDP per capita on obesity is positive at low levels but turns negative at higher levels. The coefficients of percentage of urban population, percentage of female labour participation, percentage of population age 65 and above, and the index for social globalization through information flows are all associated with increased obesity rates. Surprisingly, a higher share of trade in GDP (% trade/GDP) has a negative effect on obesity rates which also persists if this variable is replaced by an economic openness index from the KOF indices ("Actual flows", see KOF, 2017). Thus, we find openness to international trade to be obesity-reducing. In contrast, de Vogli, Kouvonen and Gimeno (2014) and Ljungvall (2013) find no statistically significant effect of openness and of some "freedom to trade internationally" index, respectively. de Vogli, Kouvonen, Elovainio and Marmot (2014) find a positive effect of economic globalization on BMI. One potential explanation is that while integration with international markets increases availability and decreases general price levels of NOVA 4 products, it does the same for less processed food options – e.g. affecting the availability and prices of vegetables out of season.

The two indicators for global developments both have the expected signs. A higher FPI, implying agricultural commodities have become more expensive relative to manufactures, is associated with higher obesity prevalence. This might be attributed to the shift in relative prices which drives consumers to substitute some of their NOVA 1 to 3 products with NOVA 4 products. Likewise, the percentage of NOVA 4 in total global NOVA 1 to 4 import value is associated with increased obesity rates.

Table 3: Regression results

Dependent variable	% obesity			% under-weight
	(1)	(2)	(3)	(4)
$dTariff_{N4\text{-}N123}$	-0.1781***	-0.1794***		0.0557***
	(0.0340)	(0.0344)		(0.0153)
$dTariff_{N34\text{-}N12}$			-0.1798**	
			(0.0708)	
$Tariff_{N4}$		0.0012		
		(0.0048)		
ln(GDP/capita)	1.8540**	1.8645**	1.9567**	-3.1529***
	(0.6916)	(0.6966)	(0.6998)	(0.3830)
$\ln(\text{GDP/capita})^2$	-0.4061**	-0.4080**	-0.4359**	0.4639***
	(0.1352)	(0.1360)	(0.1379)	(0.0635)
FPI	0.0160***	0.0160***	0.0161***	-0.0027***
	(0.0011)	(0.0011)	(0.0011)	(0.0004)
% urban	0.1939***	0.1940***	0.1903***	-0.1106***
	(0.0262)	(0.0262)	(0.0266)	(0.0121)
% female labour participation	0.0824***	0.0824***	0.0857***	-0.0079
	(0.0160)	(0.0160)	(0.0156)	(0.0060)
% trade/GDP	-0.0123***	-0.0123***	-0.0123***	0.0036***
	(0.0021)	(0.0021)	(0.0021)	(0.0007)
% age $\geq$ 65	0.4605***	0.4616***	0.4934***	0.0836***
	(0.0872)	(0.0873)	(0.0835)	(0.0239)
Information flows	0.0382***	0.0381***	0.0366***	-0.0151***
	(0.0115)	(0.0115)	(0.0115)	(0.0033)
Global % $imports_{N4}$	0.2941***	0.2937***	0.2943***	-0.0568***
	(0.0345)	(0.0346)	(0.0350)	(0.0127)
$dTariff_{N4,N123} \times$LI_SSA	0.1644**	0.1654**	0.1668**	-0.0536**
	(0.0343)	(0.0345)	(0.0709)	(0.0153)
$dTariff_{N4,N123} \times$LMI_SSA	0.1742**	0.1756**	0.1745**	-0.0487**
	(0.0351)	(0.0354)	(0.0713)	(0.0158)
$dTariff_{N4,N123} \times$LI	0.0994	0.0994	0.0943	-0.1667***
	(0.0817)	(0.0817)	(0.1029)	(0.0280)
$dTariff_{N4,N123} \times$LMI	0.1693***	0.1694***	0.1652**	-0.0571***
	(0.0340)	(0.0341)	(0.0709)	(0.0152)
$dTariff_{N4,N123} \times$UMI	0.1547**	0.1564**	0.1570**	-0.0612***
	(0.0366)	(0.0373)	(0.0722)	(0.0155)
$dTariff_{N4,N123} \times$HI	0.1958***	0.1969***	0.1824**	-0.0624***
	(0.0360)	(0.0362)	(0.0715)	(0.0157)
Observations	600	600	600	600
R^2	0.7278	0.7278	0.7240	0.7061
Adjusted R^2	0.6631	0.6624	0.6584	0.6362

Note, interaction effects for $dTariff_{N34\text{-}N12}$ are shown in the corresponding rows for $dTariff_{N4\text{-}N123}$. Source: Own computation. Symbols $^{\cdot}$, *, **, and *** indicate coefficients significantly different from zero at level 0.1, 0.05, 0.01, and 0.001, respectively.

Our main variable of interest is the dTariff variable. To allow the effect of dTariff to vary according to the state of development of the country, it is interacted with binary variables specifying the corresponding World Bank income group and whether it is an SSA country or not, as summarized in Table 1. The reference category is upper-middle-income (UMI) SSA and is associated with a negative effect on obesity prevalence. All interaction terms except low-income (LI) non-SSA are statistically different from zero, indicating that dTariff's effect on these country groups differs from that on UMI SSA. Indications that the factors which dominate the influence on BMI differ with income levels of countries are also given – for instance, in McLaren (2007) and Swinburn et al. (2011), who report that obesity prevalence is higher among the richer (higher socio-economic status [SES]) population in developing countries while it is higher among the poorer (lower SES) population in developed countries. To further investigate the effects of dTariff, the partial effects are presented together with the corresponding 95 percent confidence intervals in the left panels of Figure 1.

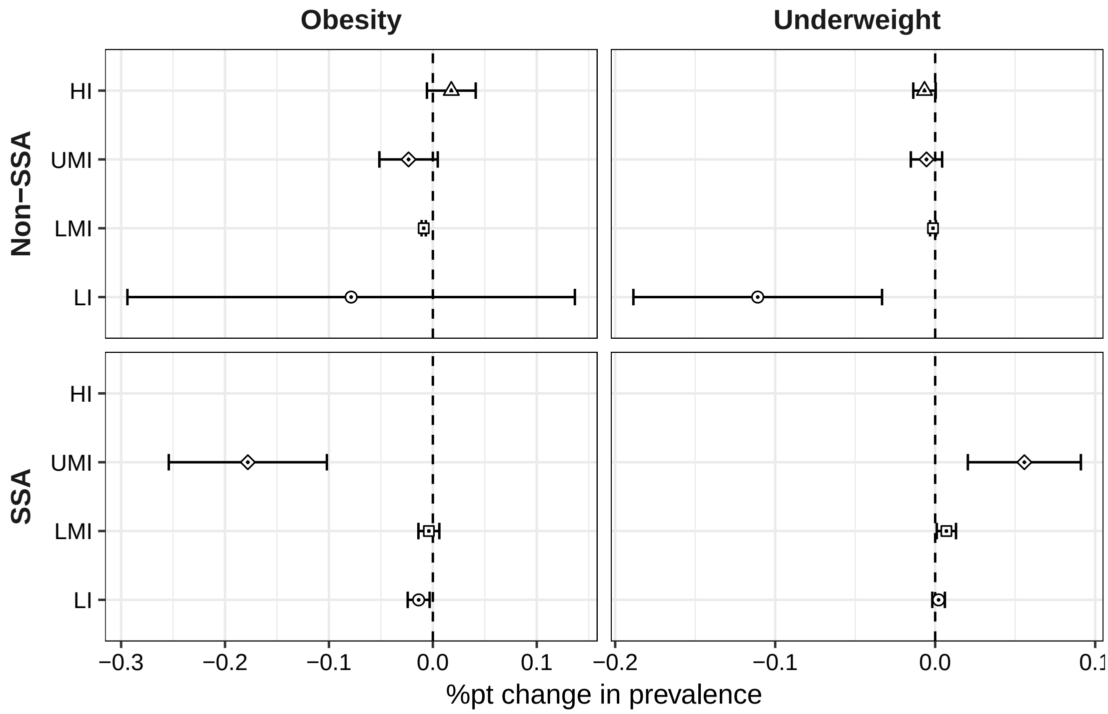

Figure 1: Marginal effects and their 95% confidence intervals in terms of the %pt change in obesity or underweight prevalence caused by a 1%pt increase in $\text{dTariff}_{\text{N4-N123}}$. Source: Own depiction.

While for LI, UMI and high-income (HI) non-SSA countries and lower-middle-income (LMI) SSA countries the estimated effects of dTariff on obesity prevalence are small and statistically not significant, as their 95 percent confidence intervals include zero, there is a sizable significant negative effect in UMI SSA of about -0.18 percentage points. This means that an increase of the difference between NOVA 4 and NOVA 1 to 3 import tariffs by one percentage point decreases the obesity prevalence rate by 0.18 percentage points. For South Africa, for example, a UMI country with a population of 53.3 million and an obesity prevalence rate of 26 percent in 2013, a 10 percentage point increase in dTariff is predicted to reduce the number of obese people by about 949 000 or 6.9 percent. Even though the measured effect for LI SSA is only -0.014, for a country like Uganda, with a population of 37.6 million and an obesity prevalence rate of 4.1 percent in 2013, a 10 percentage point increase in dTariff translates into a reduction of obesity prevalence by about 51 000 people or 3.3 percent.

Columns (2) and (3) of Table 3 check the robustness of the dTariff coefficient. Column (2) questions the choice of using the *difference* between NOVA 4 and NOVA 1 to 3 tariffs instead of using the tariff levels directly and adds a variable for the tariff level of NOVA 1 to 3. However, the variable turns out to be not statistically significant and the coefficient of dTariff changes only minimally. This provides evidence that indeed the difference between the tariff levels and not their absolute levels is decisive for the effect on obesity. In column (3), the dTariff variable is replaced by a similar tariff difference variable but between NOVA 3 and 4 and NOVA 1 and 2. If our re-classification from HS and the classification into NOVA 4 effectively delineate a group of obesity-promoting processed foods, including NOVA 3 with NOVA 4 for calculating the tariff difference should have little additional effect on the coefficient. This is confirmed by the coefficient of the $\text{dTariff}_{\text{N34-N12}}$ variable in column (3), which is only marginally larger than the $\text{dTariff}_{\text{N4-N123}}$ coefficient in column (1). The same holds for the interaction terms. In sum, these results provide additional confidence in the resilience of the effects of the dTariff variable chosen.

Finally, the estimates in column (4) are obtained using the base specification but with underweight replacing obesity prevalence as the dependent variable. As expected for most of the variables, the coefficients swap signs with this specification (apart from '% age ≥ 65'). All coefficients are significant at least at the 1 percent level, apart from '% female labour participation'. Beginning with income as the most important determinant of underweight, the estimated effects are as follows. At low levels of GDP per capita, an increase in income would reduce underweight the most. Afterwards, the effect diminishes continuously with increasing levels of GDP per capita. The variables of percentage of urban population and information flows are both associated with underweight reduction, which might result from better access to foods and information. Contrary to expectations, a higher share of trade in GDP is linked to higher underweight prevalence rates. It could be speculated that, in particular, the poorest do not benefit from the gains from trade and are negatively affected by income redistribution effects. However, the literature provides no simple answer in that direction as yet (Winters and Martuscelli, 2014). A higher percentage of population age 65 and above is also associated with higher underweight prevalence rates.

The coefficients for both FPI and global percentage of $\text{imports}_{\text{N4}}$ indicate an underweight-reducing effect and thus could point to an important role of NOVA 4 products for the nourishment of the poorest, as a higher FPI implies that prices for processed foods decreased relative to those for unprocessed foods.

The effects of the main variable $\text{dTariff}_{\text{N4-N123}}$ on underweight are examined using calculated partial effects as shown in the right panels of Figure 1. In contrast to the effect in LI non-SSA countries, which is negative and significant, the effects for LMI and UMI SSA countries are positive and significant. The estimated effects for the latter two groups are 0.007 and 0.056, respectively. Taking South Africa (population 53.3

million, of whom 5.1 percent are underweight) and Zambia (population 15.2 million, of whom 11.9 percent are underweight) as examples, and a 10 percentage point increase in dTariff, those coefficients translate into increases in underweight prevalence by about 297 000 people or 10.9 percent and about 11 000 people or 0.6 percent, respectively.

Because, in the past, obesity and underweight prevalence showed markedly different developments for women than for men in SSA, we examine gender-specific effects of dTariff by estimating the base specification using gender-specific obesity and underweight prevalence rates, respectively, as independent variables. These results are presented in Table 4.

While the directions of the effects of all variables are the same as in the overall population regressions, their sizes and significance levels differ from the previous analysis as well as between women and men. Examining the estimated effects on obesity prevalence, the most noteworthy differences between women and men are that, for men, the associated effect of GDP per capita is not significant, and the effect of percentage urban population amounts to only a fraction of that estimated for women. This suggests that the main mechanisms that are associated with obesity might be different between women and men. Turning to the results for underweight prevalence, such differences cannot be observed. The sizes as well as the significance levels of the effects are largely similar between women and men.

The partial effects of dTariff on percentage of obesity and percentage of underweight from these regressions are presented in Figures 2 and 3, respectively.

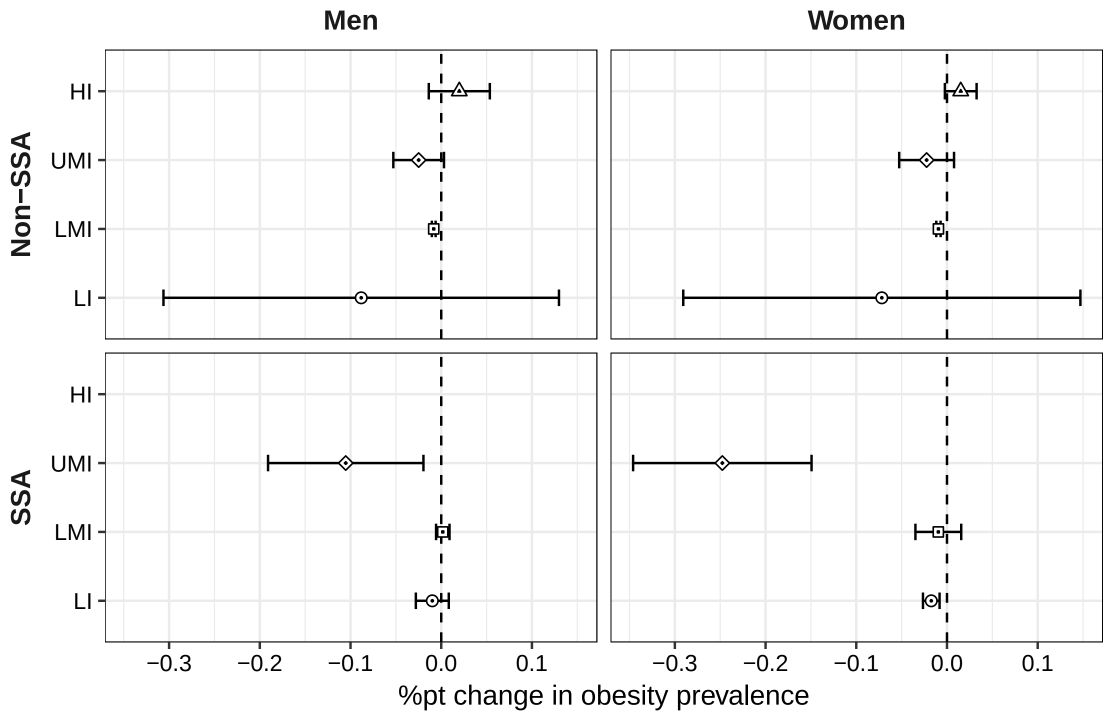

Figure 2: Marginal effects and their 95% confidence intervals in terms of the %pt change in obesity prevalence caused by a 1%pt increase in $\mathrm{dTariff}_{\text{N4-N123}}$. Source: Own depiction.

In SSA, the effects on percentages of obesity for women in LI countries (-0.02%pts) and UMI countries (-0.25%pts) are significant at the 5 percent level, and significant for

Table 4: Regression results

Dependent variable	% obesity		% underweight	
	Women	Men	Women	Men
	(1)	(2)	(3)	(4)
dTariff$_{\text{N4-N123}}$	-0.2477***	-0.1053$^{\cdot}$	0.0372*	0.0748***
	(0.0477)	(0.0336)	(0.0129)	(0.0207)
ln(GDP/capita)	3.5957***	0.1891	-3.4664***	-2.8685***
	(0.7395)	(0.7450)	(0.4237)	(0.3643)
ln(GDP/capita)^2	-0.5708***	-0.2472	0.5268***	0.4053***
	(0.1345)	(0.1491)	(0.0705)	(0.0607)
FPI	0.0147***	0.0172***	-0.0022***	-0.0032***
	(0.0011)	(0.0013)	(0.0004)	(0.0004)
% urban	0.3153***	0.0717*	-0.0800***	-0.1423***
	(0.0285)	(0.0285)	(0.0123)	(0.0128)
% female labour participation	0.0914***	0.0688***	-0.0091$^{\cdot}$	-0.0065
	(0.0165)	(0.0172)	(0.0055)	(0.0072)
% trade/GDP	-0.0128***	-0.0117***	0.0035***	0.0037***
	(0.0021)	(0.0023)	(0.0007)	(0.0008)
% age $\geq$ 65	0.1954**	0.7458***	0.0566**	0.1112***
	(0.0836)	(0.1008)	(0.0248)	(0.0260)
Information flows	0.0371***	0.0374**	-0.0129***	-0.0169***
	(0.0103)	(0.0143)	(0.0032)	(0.0038)
Global % imports$_{\text{N4}}$	0.2728***	0.3086***	-0.0476***	-0.0660***
	(0.0358)	(0.0392)	(0.0127)	(0.0139)
dTariff$_{\text{N4,N123}}$$\times$LI_SSA	0.2303***	0.0954$^{\cdot}$	-0.0350*	-0.0729***
	(0.0478)	(0.0345)	(0.0130)	(0.0207)
dTariff$_{\text{N4,N123}}$$\times$LMI_SSA	0.2381***	0.1070$^{\cdot}$	-0.0295$^{\cdot}$	-0.0685***
	(0.0490)	(0.0366)	(0.0137)	(0.0211)
dTariff$_{\text{N4,N123}}$$\times$LI	0.1758*	0.0171	-0.1750***	-0.1590***
	(0.0904)	(0.0811)	(0.0344)	(0.0260)
dTariff$_{\text{N4,N123}}$$\times$LMI	0.2382***	0.0970$^{\cdot}$	-0.0390*	-0.0758***
	(0.0477)	(0.0336)	(0.0129)	(0.0207)
dTariff$_{\text{N4,N123}}$$\times$UMI	0.2252***	0.0804	-0.0406*	-0.0823***
	(0.0497)	(0.0363)	(0.0132)	(0.0210)
dTariff$_{\text{N4,N123}}$$\times$HI	0.2628***	0.1252*	-0.0431*	-0.0821***
	(0.0487)	(0.0369)	(0.0133)	(0.0212)
Observations	600	600	600	600
R^2	0.7365	0.6838	0.6812	0.7019
Adjusted R^2	0.6738	0.6087	0.6054	0.6311

Source: Own computation. Symbols $^{\cdot}$, *, **, and *** indicate coefficients significantly different from zero at level 0.1, 0.05, 0.01, and 0.001, respectively.

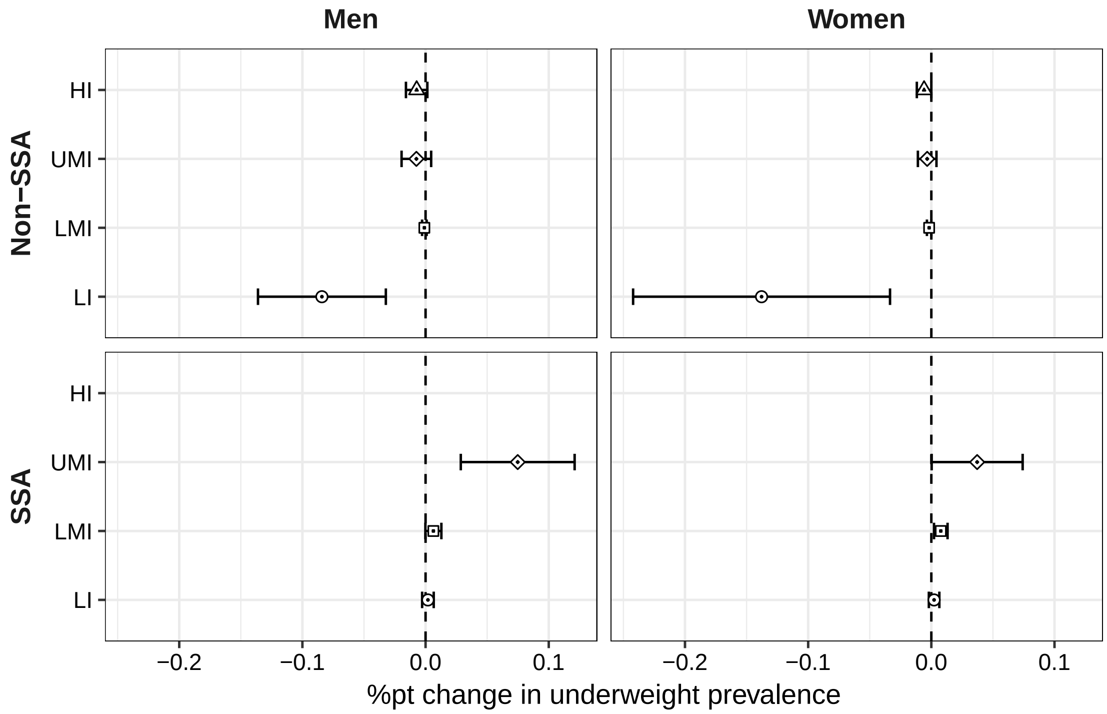

Figure 3: Marginal effects and their 95% confidence intervals in terms of the %pt change in underweight prevalence caused by a 1%pt increase in $\mathrm{dTariff}_{\text{N4-N123}}$. Source: Own depiction.

men only in UMI countries (-0.11%pts). According to these estimates, a 10 percentage point increase in dTariff in South Africa (where 50.9% of the population is female) is predicted to reduce female obesity prevalence by about 648 000 women or 6.6 percent and to reduce male obesity prevalence by about 276 000 men or 7.6 percent. Equivalently, such an increase in dTariff in the LI country Uganda (population 37.6 million, 4.1% obese, 50% female) is predicted to reduce female obesity prevalence by about 33 000 women or 2.5 percent.

Investigating the partial effects for underweight prevalence as shown in Figure 3, the effects in SSA for women in UMI (0.04%pts) and LMI countries (0.008%pts) and for men in UMI countries (0.07%pts) are significant at the 5 percent level. Accordingly, a 10 percentage point increase in dTariff in South Africa is predicted to increase female underweight prevalence by about 97 000 women or 11.2 percent and male underweight prevalence by about 196 000 men or 10.7 percent. In the case of Zambia, classified as LMI, this amounts to an increase in female underweight by about 5 800 women or 0.81 percent.

Some limitations of this study need to be mentioned. Since sales tax and consumer price data are not comprehensively available at a global level and are even scarcer for developing countries, we have utilized import tariff data. While this approach allows us to draw direct conclusions about the effects of trade policy changes on obesity and underweight, drawing conclusions with respect to the effects of food taxes more generally requires adopting strong assumptions. Moreover, during the process of re-classifying, not all HS 6-digit import tariff codes could be uniquely mapped to the four NOVA categories and thus were subject to judgement. This creates some degree of noise in the final panel dataset used. In addition, as noted by Gibney et al. (2017), the NOVA classification's definition of ultra-processed foods is "too broad and too rigid" (p. 719) to define foods' nutritional and particularly obesogenic properties and thus using the NOVA classification creates some noise in the data with respect to obesity drivers. Finally, in view of data available in our full dataset, we extracted a panel consisting of 7 years and 101 countries, including 23 countries in SSA, from the full dataset to have a balanced panel dataset including a substantial number of SSA countries with most of the desired variables. A larger dataset would yield stronger results.

Nevertheless, we are convinced that our study provides a useful contribution to the extremely thin literature examining tax policies on processed foods to support the reduction of obesity and underweight prevalence. The novel concordance developed between the HS codes and the NOVA classification enabled us to comprehensively investigate the effects of import tariffs on all highly processed foods with respect to obesity and underweight on a global scale and also to draw some more general conclusions on what effects sales taxes might have to that end.

4 Conclusion

The present study contributes to the literature assessing the potential of food taxes to limit the prevalence of obesity in SSA. Specifically, adopting a novel concordance which maps the Harmonized System import tariff data classification to the NOVA classification of food according to processing levels and relying on econometric techniques, it estimates the effects of higher import tariffs on ultra-processed foods categorized as NOVA 4 *vis-à-vis* tariffs on less processed NOVA 1 to 3 foods with respect to obesity and underweight prevalence.

The study finds that such tariff differences (dTariff) tend to be associated negatively with obesity and positively with underweight prevalence rates. However, the effects are statistically significant only for particular country groups, genders and/or regions and also differ in magnitude. Focusing on SSA, the magnitude of the estimated effect is substantial in some cases. In accordance with differences in obesity developments between women and men in the past, our results also suggest that the obesity-causing mechanisms differ by gender. These results are consistent with previous studies by Nettle et al. (2017), Swinburn et al. (2011) and McLaren (2007), for example. The tariff difference tends to be associated with larger obesity-decreasing effects for women than for men and larger underweight-increasing effects for men than for women.

In summary, the results presented indicate that the increase of dTariff can be an effective measure for reducing obesity but also highlight that such policy needs to be applied carefully. On the one hand, lower-income consumers might be more predisposed towards obesity, but the lower the income of consumers the more sensitive they are to food prices[5] and thus taxing processed foods will be most effective in those population groups. On the other hand, highly processed, energy-dense foods may have become

[5]According to Clements and Chen (1996), the negative relationship of price elasticities of food demand with income is a direct consequence of Engel's law. These authors also provide empirical evidence as do, for example, Green et al. (2013) in a meta-analysis.

important sources of calories for the poor and policies aimed at making them more expensive could push this category of poor consumers towards underweight. Moreover, considering typical properties of highly processed foods such as ease of storage, long shelf-life and high energy density, these foods might be also very important for food security in times of scarcity.

What are the implications for policy that emerge from these results? First, further efforts to liberalize trade, particularly in developing countries where current import tariff levels are still comparatively high, might counter the efforts to combat obesity but support those to combat underweight. This is because in most countries tariffs on NOVA 4 foods are higher than on other foods and a reduction of the difference between tariffs on NOVA 4 and other foods will tend to decrease underweight but at the same time to increase obesity.

Second, tax and subsidy policies to influence consumption behaviour towards healthier eating will likely be implemented not at the border but rather directly on retail sales. The price differences between highly processed and less-processed foods on retail markets are only equal to those differences directly created by dTariff at the border under the assumptions of a small country, perfect competition and availability of imported substitutes for all domestically produced foods. However, imperfect competition and transport and transaction costs prevail in developing countries' markets and might affect the pass-through of tariffs to retail prices. Therefore, consumption taxes applied directly at the retail market are likely to be more effective although they could not be studied here. If we generalize our results to analogue sales tax differences, we expect the effects on obesity and underweight to be stronger. Nevertheless, given the magnitude of the effects estimated, food taxes need to be very substantial to have a notable impact. This was also suggested by other research in the context of improving diets and reducing obesity, where tax rates of at least 20 percent were discussed (Thow et al., 2018).

Third, obesity and undernutrition cannot be treated as separate problems, particularly in developing countries. A food tax instrument as studied here will always mitigate one problem and deteriorate the other. Thus, an integrated approach, using multiple policy instruments and accounting for the side effects, is required. For instance, earmarked taxes on highly processed foods could be used to fund programmes to reduce undernutrition, as discussed in Williams (2016). Such programmes would need to be well targeted at the undernourished population to avoid incentivizing additional consumption of energy-dense foods by already well-nourished individuals or reducing input costs for the production – and thus the prices – of highly processed foods themselves.

In the future, additional research should be directed at the identification of food groups that can be targeted by taxes to combat obesity while avoiding detrimental effects on undernutrition. For this purpose, cross-classifying the NOVA classification with criteria related to nutrients or food uses appears to be a promising approach.

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