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Consumer expenditure, elasticity and value of food waste: A Quadratic Almost Ideal Demand System for evaluating changes in Mexico during COVID-19☆

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ABSTRACT

Household food waste is driven by consumer habits and behaviors. The necessary measures implemented during the lockdown worldwide to contain the Covid-19 pandemic altered these consumer practices. This paper examines how household's culinary traditions and food management have changed in Mexico as a result of Covid-related restrictions, and their impact on food waste. We obtained 525 answers using an online survey about food habits distributed through social networks in Mexico between December 2020 and January 2021. The results show that the participating households increased their monetary expenditure on groceries and reduced food waste during the pandemic. The estimation of consumer responsiveness to waste, through the introduction of a framework based on a Quadratic Almost-Ideal Demand System, confirms that, even more during the lockdown, food waste has become a luxury good. The analysis of food category changes allows for a detailed study useful to curtail the level of food waste in Mexican households and to encourage transition towards sustainable and circular consumption behaviors.

1. Introduction and background

The pandemic induced by Covid-19 and the related restrictions to limit its contagion has put the entire agri-food system under pressure. Producers are throwing away tons of fresh food due to the disruption of supply chains, the overnight closure of food services, and the lack of farmworkers and gatherers available for collecting produce [1,2]. This temporary impossibility of selling goods, doing *business as usual*, has increased food loss in the supply chain. More worrying, though, is that according to Laborde et al. [3], the pandemic is affecting the four pillars of food security: availability, access (having the most direct and crucial impact), utilization (concerning adequate nutrients), and stability (the possibility to access food permanently). However, in the face of growing difficulty in coordinating the numerous activities and disruptions of the food chain, at the consumer level the situation is different as most people were forced to stay indoors and eat the majority of their meals inside.

The lockdown imposed by governments has demanded a shift in food management practices within households. It has pushed people to avoid supermarkets [4], increase home cooking, improve meals planning by outlining grocery lists, and enhance control over food stocks [5–7]. Furthermore, the awareness of the phenomenon has grown [8], favoring a reduction in household food waste [5,6,8,9], particularly among youths [6,7]. Admittedly, households that started implementing virtuous food management practices (such as making a grocery list and planning meals) reduced food waste (FW) during the pandemic. Being able to shop at most once or twice a week during the period of restrictions has led most people to manage their domestic food consumption more carefully and, consequently, to reduce waste.

Extensive literature reviews on consumer FW research agree upon identifying some typical household features that are more or less likely to influence FW. First, there is a personal dimension linked to socio-demographic factors, knowledge about FW, and personal beliefs [10], which is also influenced by social norms and the cultural context where the people live [11]. Second, the complexity behind food management practices includes food planning, shopping, storing, cooking, and eating habits [10,11]. These dimensions are often connected to the type of

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foods that are handled in the household environment.

If we wanted to represent the profile of the family that is more likely to waste food at home, based on the available information in consumer FW literature, we would find scarce conclusive details about its demographic features. One is that smaller households produce less waste than larger ones while the amount of FW generated per capita decreases with increasing household size [10,12–15]. Another is that households with children tend to produce more waste [15,16]. There are contrasting findings regarding the role of gender, age, education, and income on the quantity of FW produced in households [10]. Instead, a much clearer picture is derived when personal beliefs are considered. In particular, the concern about FW is a predictor of its reduction [17] and can increase a person's intention to avoid waste at home [16,18]. At the same time, people concerned about saving money are more careful in avoiding waste at home [18]. However, the extent to which these intentions can be translated into practice has not been assessed. A significant gap between attitude and behavior likely exists in the FW domain [19], as is the case for other environmentally-related issues.

Moving to the second dimension of household features linked to the quantity of waste generated by consumers, it is worth underlying that a bulk of research exists about the behaviors that can increase or decrease FW's amount. Food-related practices and routines play a crucial role —probably, much more important than socio-demographic features— in determining the quantity of household FW. Lack of planning [15,20], overprovisioning [12,16,21], improper storage at home [21] have been found as significant predictors of wasteful behavior [10]. Cooking and eating habits also play a role: Aschemann-Witzel et al. [22] underline the importance of cooking skills in identifying segments of consumers with a different approach to FW, finding that people with higher cooking skills are less likely to waste food. Cooking skills and frequency can also influence the habits to reuse leftovers [18], thus avoiding losing them. Besides, individuals who frequently eat out of home tend to produce more waste at home [12].

Current consumer FW research agrees upon the food categories that are most often wasted at home. Fruits, vegetables, and bread are the top-wasted products [12,23,24], although the prevalence among these categories depends very much on the dietary preferences of the households [24]. Silvennoinen et al. [25] report that 18% of waste detected in a sample of Finnish households consist of cooked meals.

Most of these studies have focused on avoidable FW [26]. Therefore, limited information is available about the inedible parts of food discarded while preparing and cooking foods (the so-called possibly avoidable or unavoidable FW, depending on the cases) [26]. The few studies investigating this issue ([24], among others) suggest that the more educated and attentive households mostly discard unavoidable or possibly avoidable waste, although its exact quantification is not available.

To complete the overview of household FW features, we should mention that consumers act in a social, economic, and technical context that is likely to affect their waste-related behavior [11]. Significant geographical differences in the quantity of FW produced all along the supply chain exist; for example, waste in Europe and North-America is considerably higher than in Sub-Saharan Africa and South/Southeast Asia [27]. Moreover, in developing or low-income countries, FW is mainly associated with the earlier stages of the food supply chain, while in medium- and high-income countries, the consumption stage represents up to half the total FW [27,28].

According to the World Bank, Mexicans waste 20.4 million tons of food yearly, equivalent to 34.5% of the total produced foods considering all the stages of the supply chain [51]. These rough estimates underscore that the economic costs reach 2.5% of Mexico's GDP. In a context enclosed by the Covid-19 pandemic, the estimations for the country could be modified. However, no data is available about the share of this waste generated in the household environment.

In this paper, we present the results of an online survey applied in Mexico during December 2020 and January 2021. Even though we are aware of the non-probabilistic strategy for collecting our sample, the pandemic's conditions and constraints made this approach the best way to fill the information gap while ensuring the safety of respondents [29]. Indeed, our approach contributes to the relevant literature by providing a first attempt to quantify FW within Mexican households. Moreover, by estimating and studying FW value inside households and consumer responsiveness, we provide a proxy of FW's actual value in economic terms —an underexplored research area. The definition of a demand-side perspective enables us to place FW in the context of elasticities and assess its total expenditure changes, the value of waste generated, and price changes.

The rest of the paper proceeds as follows. In section 2, we present the QUAIDS methodological framework. Section 3 describes the study design and the questionnaire. Section 4 shows the survey's statistical analysis, whereas, in Section 5, we present the QUAIDS results. Finally, sections 6 and 7 discuss and conclude the food waste implications of Covid-19 in Mexico, respectively.

2. Methodological framework

In their seminal paper, Deaton and Muellbauer [30] introduced the Almost-Ideal Demand System (AIDS) for analyzing consumer spending decisions. Banks et al. [31] extended it by including a quadratic term in log expenditure, as they argued that a log-linear expenditure does not accurately depict consumer behavior on some goods. The new specification became known as a Quadratic Almost-Ideal Demand System (QUAIDS). Banks et al. [31] claimed that AIDS is a particular case of QUAIDS and showed that having a quadratic model makes the analysis more general and flexible.

For our food waste analysis, we take both Deaton and Muellbauer [30] and Banks et al. [31] specifications. However, in the following sections, we present the results of the QUAIDS specified model exclusively.[1] As defined by Deaton and Muellbauer [30], the demand function takes the following form:

$$w_i = \alpha_i + \sum_j^k \gamma_{ij} \log p_j + \beta_i \log\left(\frac{m}{a(p)}\right) \tag{1}$$

where α_i, γ_{ij} and β_i are vectors of parameters, w_i is the expenditure share for good i, m is total expenditure, and where the price index $a(p)$ is defined as:

$$\log a(p) = \alpha_0 + \sum_k \alpha_k \log p_k + \frac{1}{2}\sum_j \sum_k \gamma_{kj} \log p_k \log p_j \tag{2}$$

On the other hand, the quadratic model of Banks et al. [31] takes the indirect utility function as:

$$\ln V(p,m) = \left[\left\{\frac{\ln m - \ln a(p)}{b(p)}\right\}^{-1} + \lambda(p)\right]^{-1} \tag{3}$$

where ln a(p) is the transcendental logarithm function:

$$\ln a(p) = \alpha_0 + \sum_{i=1}^k \alpha_i \ln p_i + \frac{1}{2}\sum_{i=1}^k \sum_{j=1}^k \gamma_{ij} \ln p_i \ln p_k \tag{4}$$

In which p_i is the price of good i for $i = 1, \ldots, k$. Moreover, in the indirect utility function, $b(p)$ is the Cobb-Douglas price aggregator:

$$b(p) = \prod_{i=1}^k p_i^{\beta_i} \tag{5}$$

and

[1] We use both QUAIDS and AIDSILLS commands of [32] in STATA. In the paper we only present the results of QUAIDS. AIDSILLS estimations are available upon request.

$$\lambda(p) = \sum_{i=1}^{k} \lambda_i \ln p_i \tag{6}$$

In line with the economic theory requirements, aggregation, homogeneity, and symmetry restrictions need to be either imposed or tested, and these imply that:

$$\sum_{i=1}^{k} \alpha_i = 1, \quad \sum_{i=1}^{k} \beta_i = 0, \quad \sum_{i=1}^{k} \gamma_{ij} = 0, \quad \sum_{i=1}^{k} \lambda_i = 0, \quad \gamma_{ij} = \gamma_{ji}$$

An advantage of using the QUAIDS command in STATA is that, according to Poi [32], it enforces the required conditions automatically.

2.1. Elasticities

As the estimated parameters are not of primary interest for the analysis, we do not report them in the following sections.[2] Instead, we present the estimated expenditure and uncompensated price elasticities to focus our discussion on the economic interpretation. To estimate the elasticities, we take the following equations:

$$\mu_i = 1 + \frac{1}{w_i}\left[\beta_i + \eta_i' z + \frac{2\lambda_i}{b(p)c(p,z)} \ln\left\{\frac{m}{\overline{m_0}(z)a(p)}\right\}\right] \tag{7}$$

which is the expenditure elasticity for good *i*, and the

$$\varepsilon_{ij} = -\delta_{ij} + \frac{1}{w_i}\left(\gamma_{ij} - \left[\beta_i + \eta_i' z + \frac{2\lambda_i}{b(p)c(p,z)} \ln\left\{\frac{m}{\overline{m_0}(z)a(p)}\right\}\right] \times \left(\alpha_j + \sum_l \gamma_{jl} \ln p_l\right) - \frac{\left(\beta_j + \boldsymbol{\eta_j' z}\right)\lambda_i}{b(\boldsymbol{p})c(\boldsymbol{p},\boldsymbol{z})}\left[\ln\left\{\frac{m}{\overline{m_0}(z)a(\boldsymbol{p})}\right\}\right]^2\right) \tag{8}$$

which is the uncompensated price elasticity of good *i* for changes in the price of good *j*. In Eqns (7) and (8), the terms η and $m_0(z)$ *bar* are a vector of *s* characteristics and the expenditure function scaled by considering the demographic characteristics (z), respectively. Finally, the compensated price elasticities were derived from: $\varepsilon_{ij}^C = \varepsilon_{ij} + \mu_i w_j$ —the Slutsky equation.

3. Study design

3.1. Data collection process

Bearing in mind our study's aim, we implemented an ad-hoc survey, and we asked participants to answer by thinking about their homes, urging them that whoever responded was the main responsible for doing the groceries and preparing meals daily. The survey was uploaded on Google Forms, where its central purpose was to understand consumers' food-related behaviors before and during Covid-19. Moreover, we asked participants whether the lockdown had an impact on their FW level. The self-reported data about FW in surveys has become a standard instrument for estimations [23,33,34]. The discussion regarding FW's underestimation using this tool is back and forward [35,36]. Our study opts for using self-reported FW across time, in two different moments, as it has been suggested as a proper measure [20].

We gathered the data in December 2020 and January 2021 in Mexico through social networks like Facebook, LinkedIn, and Twitter. In the survey, we asked people to estimate their FW level both at the time of the interview and before the Covid-19 pandemic (making reference to the same period of the previous year, that is December 2019 and January 2020), by food category. For this purpose, we built ten food categories: 1) Fruits, 2) Vegetables, 3) Beef, chicken, and pork products, 4) Fish and shellfish, 5) Milk, yogurt, and dairy products, 6) Eggs and cheese, 7) Tortilla, rice, cereals, and pasta, 8) Bread and pizza, 9) Seasonings, such as mayonnaise, mustard and other seasonings, and 10) Desserts. We obtained each category's prices from the National Institute of Statistics and Geography (INEGI, for its acronym in Spanish) for building the elasticity estimations.[3] Since we asked participants to estimate their FW level before and during the pandemic, we selected the prices from INEGI for December 2019 and December 2020, respectively. We also asked them to estimate their total weekly expenditure on groceries by household, before and during Covid-19. It is worth mentioning that respondents were located throughout Mexico. Therefore, each price corresponds and is detailed for their place of residence by state.

3.2. Questionnaire

The survey consisted of 41 single and multiple-choice questions distributed along four sections. Each section was extracted from the most recent literature on FW by considering: 1) Situational, psychological, and social factors; 2) Purchasing habits and behaviors; 3) Waste management practices, and 4) Household socio-demographic characteristics. For a detailed discussion regarding the match between our sections and the relevant literature, refer to Principato et al. [6].

In general, we took the Household Wasteful Behaviour Framework (HWBF), which supports a multifactorial analysis of FW [37]. This framework includes situational, psychological, social factors, habits, behaviors, practices, and demographic characteristics. All of which remain central elements for explaining FW in households [10,15,16,18,38–41].

In this study, we asked participants whether FW is important for themselves, their relatives, and the place they reside. Moreover, they informed us of the frequency they do groceries, the distribution channel of their preference, and whether they felt their consumer practices changed during the pandemic. Additionally, we asked them to reflect on why they wasted food and their preventive measures before and during Covid-19. Finally, we asked them traditional demographic questions (i.e., age, gender, education level, etcetera).

3.3. The specified QUAIDS models

According to Poi [32], the specified models that the QUAIDS command uses in STATA could be derived with or without demographic variables. The demographic variables are considered by following Ray [42] and extending on Poi [43]. As detailed, these socio-demographic variables are included in a vector *z* representing *s* characteristics.

For these models, we specified two variants: the first for the classical total expenditure and the second for the novel approach of the *Value of Food Waste*. In both variants, we used w_i as the amount of each category's FW, as defined in the Data collection process in the previous section. Recall that w_i is the amount of FW where $i = 1, \ldots, 10$. Moreover, we used p_i as each category's price depending on the household's state.

We built the variable *Value of Food Waste* by multiplying the amount

[2] Just like the estimates of AIDSILLS, the parameters may be shared upon request. In general, the parameters are estimated precisely.

[3] Access INEGI's site at https://www.inegi.org.mx/app/preciospromedio/?bs=18.

of overall weekly food waste with groceries' expenditure. In other words, the *Value of Food Waste* from each household is the amount they spend on groceries that they estimate to waste. In the description of our results, we consider them both in terms of total expenditure (i.e., as in traditional elasticity analysis) and as *Value of Food Waste*, a novel approach to the analysis.

4. A descriptive analysis of the data

A total of 538 households answered our survey. However, after validating that people responded correctly to the questions, we dropped 13 observations because some were repeated (n = 9) or their answers incoherent (n = 4). Thus, the definitive database analyzed tallied 525 observations (see Table 1).

In general, many of the people who responded to our survey live in Mexico City's Metropolitan Area (n = 225, 42.9%), whereas the rest are distributed amid 28 states.[4] Mexico City's Metropolitan Area comprises three states: Mexico City, the State of Mexico, and one municipality in Hidalgo. According to the answers, most respondents had 38 years on average, were living in a household size of 3.9 inhabitants, with 1.9 of those receiving an income. Additionally, the majority of the respondents were women (n = 413, 78.7%), with a single marital status (n = 205, 39.0%), who completed a bachelor's degree (n = 226, 43.1%), lived in an urban area (n = 472, 89.9%), and were currently employed (n = 273, 52%). Moreover, we obtained answers from every income decile (See Fig. 1).

When asked about their weekly monetary expenditure on groceries, a household's average weekly expenditure was 68.84 USD[5] (Std. Dev. = 56.69) before Covid-19 and 80.20 USD (Std. Dev. = 65.88) during the pandemic with a statistically significant difference (diff = −11.36, *p-value*<0.01). Furthermore, the empirical quartiles observed before and during the pandemic were: $Q_{1Before}$ = 38.35 vs. $Q_{1During}$ = 40.74; $Q_{2Before}$ = 47.94 vs. $Q_{2During}$ = 71.91; and $Q_{3Before}$ = 95.88 vs. $Q_{3During}$ = 95.88. In other words, we observe that households increased their expenditure on groceries during the pandemic. One plausible reason is that people transferred the amount of money they spent outside their households and consumed it inside during the pandemic. This explanation is strengthened as participants shared the number of meals (i.e., breakfast, lunch, and dinner) they had inside their households before and during the pandemic. People had 16 meals from 21 in their households before the pandemic and almost 19 meals during the lockdown every week, with a statistically significant difference (diff = 2.7, *p-value*<0.01).

Table 1
Demographic characteristics.

Variable	Value	Std. Dev.	Min	Max	Obs.
Age (mean)	37.9	12.8	16	74	525
Household size (mean)	3.9	1.8	0	22	525
People w/income (mean)	1.9	0.9	0	7	525
Female (% of respondents)	78.7				525
Level of education (% of respondents)					
Elementary	2.6				14
Secondary	5.9				31
High School	18.3				96
Bachelors	43.1				226
Masters	15.4				81
Doctorate	14.7				77
Marital status (% of respondents)					
Married	38.3				201
Divorced	6.3				33
Single	39.0				205
Free union	13.7				72
Widow	2.7				14
Residence state (% of respondents)					
Mexico City's Metropolitan Area	42.9				225
Other	57.1				300
Area of residence (% of respondents)					
Rural	10.1				53
Urban	89.9				472
Job status (% of respondents)					
Employed	52.0				273
Other	48.0				252

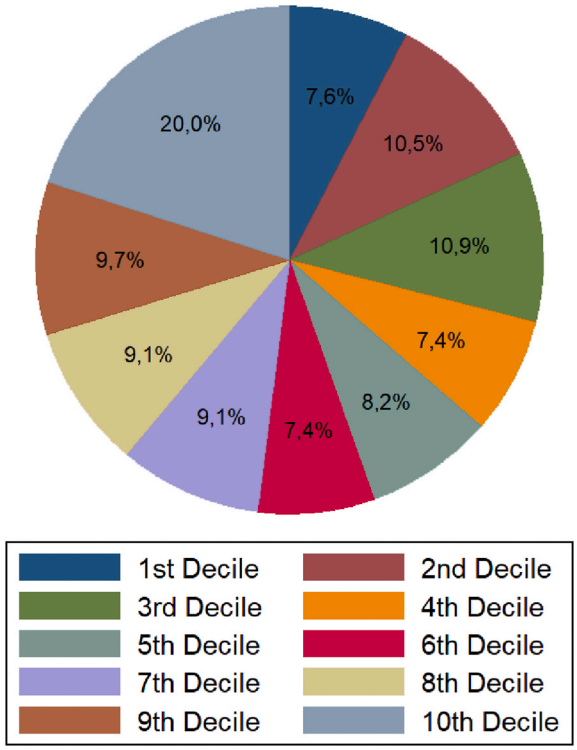

Fig. 1. Income distribution.

Before Covid-19, the most frequently cited distribution outlets for obtaining groceries were: 1) the Supermarket, 80%; 2) Small businesses, 67%[6]; and 3) Markets, 46%. During the pandemic, households did not change the order of the latter outlets. Nevertheless, people who relied on online purchases went from 4% to 24% during the pandemic (diff = −0.19, *p-value*<0.01). Our hypothesis, and one which remains to be tested, is that the increase of online purchases was triggered during the pandemic globally. Put differently, people with access to a reliable Internet connection began to opt for previously overlooked options based on this technology. A feasible explanation is the compliance of measures during the lockdown, which left the alternatives at a second or third place due to the sanitary concerns given the physical presence requirement.

Respondents reported that before the pandemic, they usually went to buy groceries once per week (41%), followed by 2–3 times per week (26%), and once every other week (15%). In contrast, during the lockdown, people continued going once per week as their primary option (41%), but instead of increasing the frequency (i.e., daily or 2–3 times per week), they switched to going mainly every other week (15%–28%, diff = -0.13, *p-value*<0.01) or even once per month (3%–9%). These results show that people planned their meals with a more extended timeframe during the pandemic to remain at home as long as possible. Additionally, when asked about their planning habits through shopping

[4] We did not receive valid responses from the states of Nayarit and Tabasco.
[5] We converted the Mexican pesos to USD with an exchange rate of 20.86 pesos per dollar.
[6] Small businesses as butchers, small shops, grocery stores, bakeries, etcetera.

lists, only 33% of them always made a list before the pandemic, whereas 53% did it during. Moreover, those households that never used delivery services for grocery shopping dropped from 62% to 30% (diff = 0.32, *p-value*<0.01). Again, these results reveal that people changed how they do groceries, both in frequency and substance.

The question now is whether these behaviors shift modified FW. When asked about their overall FW level, respondents say that their waste was 16.3% (Std. Dev. = 13.6) of the total amount of food they bought before the lockdown began. In contrast, they also stated that during Covid-19, their waste level dropped to 13.4% (Std. Dev. = 12.8), on average. Consequently, we reject the null hypothesis that the difference of means (diff = 2.87, *p-value*<0.01) is statistically different from zero. Furthermore, by running a one-sided *t*-test, we can answer that FW dropped during Covid-19.

Reviewing the food waste level by category complements Mexican households' food waste landscape in our sample. See Fig. 2 and observe that households wasted food differently depending on the category. For instance, fish and shellfish were usually wasted way below 20%, whereas most fruits and vegetables were wasted above that portion. One interesting finding is that the level of waste observed on fruits and vegetables was in line with the literature, where they are currently reported as the top-wasted product in the household environment. On the other hand, when people think within food categories, before and during Covid-19, food waste apparently remained almost the same. This is because respondents answered the overall food waste level separately from the waste within each category. It seems that people responded

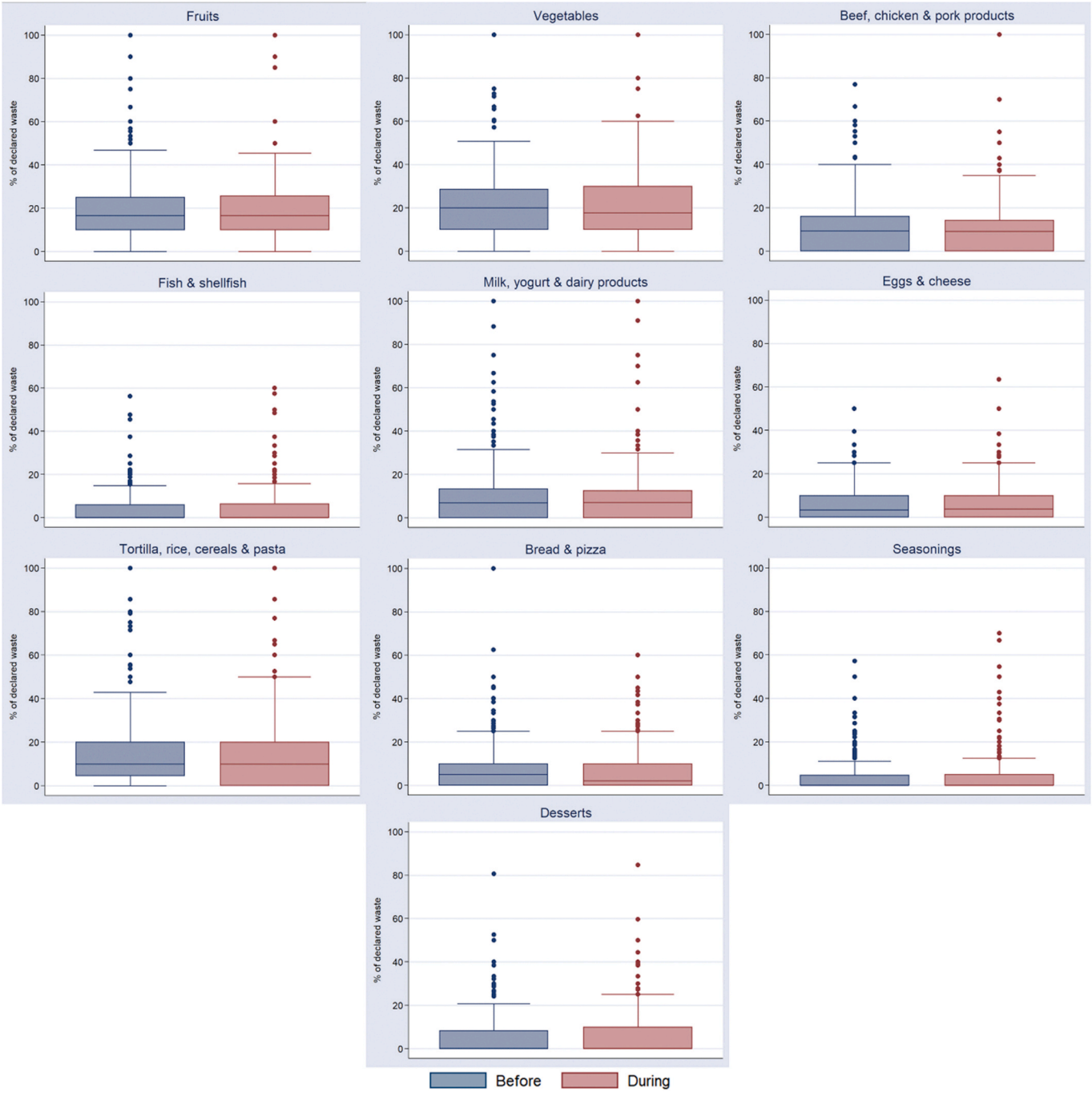

Fig. 2. Level of food waste by category, before and during Covid-19
Note: The level of food waste is the amount of waste (in percentage terms) that households estimate on each category, before and during Covid-19.

Table 2
Expenditure elasticities, before and during Covid-19.

Food category	Overall sample		Below (or equal to) the median		Above the median	
	Before	During	Before	During	Before	During
Fruits	0.976***	0.975***	1.114***	1.011***	1.128***	0.950***
Vegetables	1.115***	1.008***	1.400***	1.133***	0.864***	0.757***
Beef, chicken & pork products	0.959***	1.002***	1.061***	0.965***	0.911***	0.988***
Fish & shellfish	0.965***	1.010***	1.313***	0.672***	1.056***	1.218***
Milk, yogurt & dairy products	0.896***	0.908***	0.674***	0.848***	0.832***	1.243***
Eggs & cheese	0.898***	1.126***	0.911***	1.172***	1.152***	1.388***
Tortilla, rice, cereals & pasta	0.836***	0.833***	0.481***	0.938***	0.744***	0.822***
Bread & pizza	1.109***	1.177***	1.054***	1.195***	1.350***	1.218***
Seasonings	1.003***	0.878***	0.628***	0.516	0.944***	0.652
Desserts	1.336***	1.392***	0.865***	1.084***	1.607***	1.602***

Notes: *** = ($p < 0.01$). The median expenditure before Covid-19 is 47.94 USD with a minimum expenditure of 9.59 and a maximum expenditure of 239.69 USD. The median expenditure during Covid-19 is 71.91 USD with a minimum expenditure of 9.59 and a maximum expenditure of 335.57 USD.

differently to being asked about their overall food waste level from their waste level per category. Besides, the visual impediment that apparently food waste did not change per category before and during Covid-19 drives us to take the data and analyze it through the QUAIDS specified model.

5. Results

5.1. The demand of food waste: expenditure and cross-price elasticity

Table 2 shows the expenditure elasticity estimates based on the QUAIDS model described by Equation (7). The first set of results displayed in this table are for the total sample, whereas the second set is divided by the expenditure level that households have on groceries. The second set is arranged by those households that spend both the least and the most on groceries (i.e., below and above the median value). Both set of estimates consider the declared share of FW per category ($i = 1, \ldots, 10$) as w_i and the total weekly food expenditure as m. Additionally, we take the values before and during Covid-19 for both sets of estimates.

As usual in classical microeconomic theory, one of the most popular consumer demand measures is the income/expenditure elasticity. It is an economic measurement that informs about the percentage change in demand in response to a one percentage change in consumer income/expenditure [44]. With specific reference to consumer behavior towards FW, Secondi and Principato [45] firstly introduced the notion of expenditure elasticity towards FW (i.e., FWE2) by estimating a Working-Leser demand system and obtaining, for a case study in Italy, positive elasticity values proving that all the categories of products considered represented normal "wasted" goods, i.e., categories of food for which as food expenditure increases the percentage of food wasted increases. On the contrary, a negative value of expenditure elasticity would have identified lower (inferior) wasted goods, meaning an increase in total expenditure would decrease FW's amount for the studied category.

Bearing the above notions in mind, it is interesting to assess if and to what extent consumers' responsiveness towards each specific category of food product changes as the total household expenditure for food increases. In this sense, it is possible to distinguish between *necessity* food/goods and *luxury* food/goods by discerning among elasticity values between 0 and 1 or greater than 1. On the one hand, we define *necessity* (wasted) goods as those food categories for which a 1% of total expenditure increase generates a less than proportional increase in waste. In other words, although they represent products that consumers waste regardless of the change in their total expenditure levels, it is possible to find a smaller prevalence of these products on households with a higher economic tenure level, as approximated by the total food consumption expenditure per week. On the other hand, we define *luxury* (wasted) goods as those food categories for which FW increases more than proportionally compared to the increase of food expenditure.

The analysis of the estimated expenditure elasticity towards FW (Table 2, first set of results) can be carried out by cross-analyzing both within and between each period under study (Before and During Covid-19, respectively). Focusing on the within-analysis, we find that before the pandemic began (in our case referring to December 2019 period), the lowest expenditure elasticity was registered for "Tortilla, rice, cereals & pasta" (0.836, *p-value*<0.01) which represents a *necessity* good together with "Milk, yogurt & dairy products", "Eggs & cheese", "Beef, chicken & pork products", "Fish & shellfish" and "Fruits". *Luxury* goods, meaning those products whose share of waste (out of the total waste generated by the households) increases more than proportionally to the total food expenditure, are found to be above all: "Desserts", "Vegetables", "Bread & pizza", and slightly "Seasonings". The analysis during Covid-19 confirmed most of the relationships between food categories and consumption expenditure (*necessity* versus *luxury* goods). However, those differences registered in the two periods enable us to highlight some interesting behavioral changes.

By comparing the values of expenditure elasticity before and during Covid-19, we find that the categories: "Beef, chicken & pork products", "Fish & shellfish", and "Eggs & cheese" changed their status from *necessity* to *luxury* goods. On the contrary, "Seasonings" does the opposite. Put differently, the goods for which consumers' attitude is identified as *necessity* goods before Covid-19 have raised their elasticity during the pandemic. These changes are heading to approximately a unitary expenditure elasticity (for meat and fish) while increasing considerably for eggs and cheese whose waste is now conceived as a *luxury* good.

In Table 2, we also find the food categories for which an increase in total food expenditure still means a higher household propensity of wasting these types of food: this is the case of bread and pizza and desserts, whose waste is still more of a *luxury* good during Covid-19. With this in mind, it becomes relevant to analyze whether in-depth differences exist in food expenditure levels. In the second set of results in Table 2, we can distinguish among the households that consume less than 47.94 USD before the pandemic and less than 71.91 USD during, from the households that consume more than 47.94 USD and up to 239.69 USD before the pandemic and more than 71.91 USD and up to 335.57 USD during Covid-19.

Focusing on the changes observed between the two periods and the two household groups, a more significant difference in fresh food (i.e., fruits and vegetables) emerges. Both categories maintain the role of *luxury* goods for households below the median food expenditure (i.e., as people spend more on food, they will waste proportionally more on fruits and vegetables). However, a reversal of this trend is observed for households above the median: wasting fruits representing *luxury* goods before Covid-19 have become a *necessary* item during the pandemic, diminishing their presence as the consumption expenditure increases (ceteris paribus). These results might be derived from people planning more on their grocery shopping and spending more time at home.

A drop in the expenditure elasticity is registered for meats and, more

Table 3
Uncompensated own-price elasticities, before and during Covid-19.

Food category	m = Weekly Expenditure on Groceries		m = Value of Food Waste	
	Before	During	Before	During
Fruits	−1.553***	−0.885	−0.889	−0.597
Vegetables	−1.457***	−1.195***	−1.176***	−1.176***
Beef, chicken & pork products	−0.081	−1.323	−0.271	−1.239
Fish & shellfish	−2.070***	−1.661***	−1.940***	−1.938***
Milk, yogurt & dairy products	−1.082	−1.854***	−1.059	−1.880***
Eggs & cheese	−1.547	−0.284	−1.278	−0.426
Tortilla, rice, cereals & pasta	−0.502	−1.257	−0.254	−0.906
Bread & pizza	−0.390	−1.178***	−0.467	−1.067***
Seasonings	−0.588	−0.891	−0.495	−0.805
Desserts	0.660	−0.283	0.833	−0.302

Notes: *** = ($p < 0.01$).

drastically, for fish in the households where total consumption expenditure remains below the median. The latter could mean that people consume more fish during the lockdown. Simultaneously, an utterly inverse change is found for those families in the higher total-expenditure group. Indeed, wasting fish, milk, dairy products, eggs, and cheese has become even more of a *luxury* good during the pandemic —meaning that this type of waste's marginal contribution is still more accentuated when the level of consumption expenditure increases, ceteris paribus.

Different information may be extrapolated from estimating the uncompensated (Marshallian) own price elasticities displayed in Table 3. These estimates show the relationship between the price of the good j and the quantity of waste generated on the table's left side. We confirm the negative relationship between price and the waste generated for each product category with some crucial changes by comparing before and during Covid-19 estimated values. Expressly by focusing on the statistically significant coefficients, the demand for wasted fish and shellfish is confirmed to be elastic to price changes even when a reduction is registered. Moreover, it is essential to note that all the significant values of own-price elasticities during Covid-19 were found to be in absolute terms greater than 1, meaning an increased level of consumers' sensitiveness of demanding/producing waste depending on prices. This is the case for "Vegetables" (own-price elasticity = −1.195, *p-value* ≤ 0.01), "Fish and shellfish" (own-price elasticity = −1.661, *p-value* ≤ 0.01), "Milk, yogurt and dairy products" (own-price elasticity = −1.854, *p-value* ≤ 0.01) as well as "Bread and pizza" (own-price elasticity = −1.178, *p-value* ≤ 0.01).

5.2. A novel approach: the economic value of food waste

On the right-hand side of Table 3, we also show the estimations derived from the QUAIDS model specified in Equation (8). On the other hand, Table 4 displays the estimates of the QUAIDS model specified in Equation (7). In both tables, instead of using the total expenditure in m, we introduce an economic estimated "proxy" of the Value of Food Waste (VFW) generated in each household. As specified before, our novel approach and these results require a different interpretation of both expenditure/income elasticity and own-price elasticities.

Table 4
Value of Food Waste elasticities, before and during Covid-19.

Food category	Value of Food Waste	
	Before	During
Fruits	0.941***	0.949***
Vegetables	0.974***	0.916***
Beef, chicken & pork products	1.046***	1.115***
Fish & shellfish	1.174***	1.160***
Milk, yogurt & dairy products	1.014***	1.042***
Eggs & cheese	1.104***	1.107***
Tortilla, rice, cereals & pasta	0.898***	0.870***
Bread & pizza	1.091***	1.116***
Seasonings	1.029***	1.020***
Desserts	1.107***	1.189***

Notes: *** = ($p < 0.01$).

The expenditure-type elasticity reported in Table 4 as *VFW elasticities* enables us to investigate whether and to what extent the budget share (marginal contribution) of each food category increases when the economic values of food waste within each household increases by 1%. As previously discussed, all the estimated elasticities are positive, thus indicating that all the food categories can be considered *normal* goods. However, here it is even more important to distinguish between *necessity* and *luxury* goods.

Indeed, a VFW elasticity lower than 1 means that as FW's total economic value increases, the proportion of this economic value represented by *necessity* wasted goods typically declines. On the other hand, a VFW elasticity greater than (or equal to) 1 means that consumers/households will waste proportionately more of the specific good compared to a percentage change in FW's total economic value. Granting our interpretation, the estimated VFW elasticities could represent a more focused measure for identifying those types of food with a more significant "weight" and contribution to FW's total economic value.

According to our estimates, a general increase in the VFW elasticities before and during COVID-19 is observed while preserving for the various food categories the same type of classification (*necessity* versus *luxury* goods). Furthermore, we remark a slight increase in the VFW elasticities for those categories classified as "luxury wasted food" both before and during COVID-19. Therefore, for these food categories, as FW's total economic value increases, the proportion of waste represented by these products will go up. This is, above all, the case of meat (beef, chicken, and pork products), fish and shellfish, as well as milk, dairy products, eggs, and cheese. It is important to note that for fresh products, especially for vegetables, we register a decrease of the estimated VFW elasticity, which could be related to the more oculate purchases and the greater number of meals consumed at home.

6. Discussion

In the analysis of expenditure elasticity conducted in this paper, all categories of food showed a positive elasticity value, thus confirming these products are *normal* goods for which FW increases together with the expenditure. This result is in line with the one recently observed for the U.S. by Landry and Smith [46], where FW was considered among *luxury* goods with values of expenditure elasticity between 1.1 and 1.4.

Wealthier households are therefore likely to discard more food because they are less concerned about wasting. Simultaneously, more affluent households may experience a higher opportunity cost for the time needed in every meal preparation, thus increasing household FW [45]. This paper has studied this mechanism more in-depth by distinguishing the wasted food/goods between *necessity* food/goods, and *luxury* food/goods following their elasticity values, varying between 0 and 1 or greater than 1. An increase in the expenditure for a particular food category generates a less than proportional increase in waste if the food is of *necessity*, while the opposite applies for *luxury* goods.

Expenditure elasticities were calculated for our Mexican sample of respondents for all product categories before and during Covid-19 (with reference periods in December 2019 and December 2020, respectively). In the pre-pandemic situation, we identified "Desserts", "Bread and pizza", "Vegetables" as *luxury* goods, for which the share of waste increases more than proportionally to the total food expenditure. In the case of vegetables, this result confirms the combined effect of income and preference for a healthy diet, resulting in more waste of these products in wealthier households [47].

The classification of *necessity* and *luxury* wasted goods is mostly the

same before and during Covid-19. However, the magnitude of the elasticity does change. For example, the "Bread and pizza" category, which is listed among the *luxury* goods, shows a remarkable increase in expenditure elasticity. Such an increase may be due to the baking and preparing habits established in many households during the pandemic [6,48]. These practices may have occurred more often in high-income households, among which teleworking or smart-working is more diffused [49]. It is interesting to note that for other goods, e.g., "Eggs and Cheese", the expenditure elasticity change between the two periods resulted in a different classification of these products. They moved from *necessity* foods before the pandemic to *luxury* foods during the Covid-19 period. This change is particularly observed among households with expenditure below the median, showing that the approach to waste completely changed due to Covid-19 restrictions.

By analyzing the difference among households with expenditure above/below the median of the sample, the elasticity of fruits and vegetables shows remarkable differences. These products maintain the role of *luxury* goods for households below the median food expenditure, i.e., as people spend more on food, they will waste proportionally more on fruits and vegetables. This evidence seems in line with previous findings showing that having a healthy diet (with more fruits and vegetables) increases the quantity of FW produced in the household [47]. Interestingly, the opposite occurs for households with food expenditure above the median, where fruits and vegetables seem to have become a *necessity* good during the pandemic, contrary to what happened before. This may be explained by the pandemic's behavioral changes, with more time allocated to food planning and preparation [5,6,50]. Furthermore, for the specific cases above and below the median, interventions focusing on planning the purchase of fish, milk, dairy products, eggs, and cheese can help reduce overall FW.

In the QUAIDS models, where the total expenditure was introduced as a "proxy" of the value of FW generated in the households, the estimated VFW elasticities can be viewed as a more focused measure for the identification of the foods having a greater "weight" and contribution on the total economic value of FW. The VFW elasticities generally increased across the two periods considered for *luxury* goods, whereas it decreased for vegetables, maybe due to more oculate purchases and the greater number of meals consumed at home [6].

7. Conclusion

According to our results, FW decreased slightly during Covid-19 in Mexico. However, it is still unknown whether the behaviors that triggered its decline will prevail once the global situation returns to normality. Our study identified that people started FW preventive strategies such as writing grocery lists or using leftovers on other meals more frequently during the pandemic. It could be because individuals remained indoors more time, because they had a contraction in their income, or because the extra amount of time meant they could dedicate it to the kitchen activities without rushing.

We could speculate on the reasons behind the FWs reduction, but, at least from our study, it seems that people are slowing down inside their homes and paying more attention to their FW. Public policies that seek to enhance and normalize the household tactics initiated during Covid-19 may sustain FW's drop in the years to come. Of course, more research on the reasons behind the drop is required.

Regarding the elasticity analysis we conducted, it is clear that households reduced FW depending on the food-specific category. As we highlight, households treat some goods as *normal* and others as *luxury*. The latter is in line with the traditional economic analysis. However, in a pandemic context produced by Covid-19, Mexican households in our sample modified their FW depending on the food category and its respective *normal* or *luxury* status, which may be different to households from other parts of the world. To better understand FW, it is worth conducting this analysis on other countries to see the expected differences.

CRediT authorship contribution statement

Adrian Vargas-Lopez: Conceptualization, Data curation, Formal analysis, Investigation, Software, Methodology, Writing – original draft, Writing – review & editing, Project administration. **Clara Cicatiello:** Conceptualization, Investigation, Supervision, Writing – original draft, Writing – review & editing. **Ludovica Principato:** Conceptualization, Investigation, Supervision, Writing – original draft, Writing – review & editing. **Luca Secondi:** Conceptualization, Writing – original draft, Writing – review & editing, Supervision, Software, Methodology, Investigation, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

	I		II		III		IV		V		VI		VII		VIII		IX		X	
	Before	During	Before	During	Before	During	Before	During	Before	During	Before	During	Before	During	Before	During	Before	During	Before	During
Expenditure	0.976***	0.975***	1.115***	1.008***	0.959***	1.002***	0.965***	1.01***	0.896***	0.908***	0.898***	1.126***	0.836***	0.833***	1.109***	1.177***	1.003***	0.878***	1.336***	1.392***
Fruits	**-1.553*** **	**-0.885**	0.447	0.024	0.612	0.221	0.481***	0.447***	0.118	-0.208	0.067	-0.053	-0.784***	-0.276	-0.003	-0.175	-0.158	0.072	-0.204	-0.142
Vegetables	0.393	0.016	**-1.457*** **	**-1.195*** **	-0.541	-0.133	-0.14	0.057	0.58***	0.546***	-0.084	-0.253	0.12	-0.044	0.064	0.054	-0.094	-0.191	0.042	0.135
Beef, chicken and pork products	1.15	0.43	-1.044	-0.284	**-0.881**	**-1.323**	-0.208	-0.382	0.057	-0.319	-0.224	0.335	-0.342	0.452	-0.32	0.343	0.156	0.018	-0.103	-0.271
Fish and shellfish	2.547***	2.223***	-0.758	0.31	-0.588	-0.969	**-2.07*** **	**-1.661*** **	0.068	0.259	0.486	-0.922	1.112	0.893	-0.29	-0.025	-0.419	-0.022	-1.052	-1.096
Milk, yogurt and dairy products	0.254	-0.412	1.29***	1.238***	0.068	-0.323	0.028	0.11	**-1.082**	**-1.854*** **	0.003	0.011	-0.669	0.082	-0.531	-0.231	0.31	0.449	-0.567	0.02
Eggs and cheese	0.254	-0.2	-0.273	-0.912	-0.421	0.536	0.331	-0.598	0.006	-0.003	**-1.547**	**-0.284**	-0.169	-0.875	0.326	0.744	-0.021	-0.189	0.616	0.654
Tortilla, rice, cereals and pasta	-1.073	-0.338	0.239	-0.025	-0.243	0.32	0.299	0.244	-0.46	0.059	-0.063	-0.343	**-0.502**	**-1.257**	0.398	0.173	0.211	0.033	0.358	0.301
Bread and pizza	-0.035	-0.544	0.177	0.134	-0.459	0.486	-0.147	-0.021	-0.704	-0.349	0.224	0.665	0.696	0.327	**-0.39**	**-1.178*** **	-0.19	-0.04	-0.282	-0.657
Seasonings	-0.954	0.384	-0.581	-1.029	0.496	0.058	-0.478	-0.018	0.916	1.119	-0.041	-0.284	0.883	0.12	-0.433	-0.051	**-0.588**	**-0.891**	-0.223	-0.287
Desserts	-0.89	-0.602	0.132	0.451	-0.26	-0.539	-0.81	-0.815	-1.174	-0.007	0.666	0.726	0.955	0.746	-0.454	-0.843	-0.159	-0.224	**0.66**	**-0.283**

* Estimations without demographic variables.

Fig. 3. Expenditure & Uncompensated Elasticities (before and during Covid-19).

	I		II		III		IV		V		VI		VII		VIII		IX		X	
	Before	During	Before	During	Before	During	Before	During	Before	During	Before	During	Before	During	Before	During	Before	During	Before	During
Value of Food Waste	0.941***	0.949***	0.974***	0.916***	1.046***	1.115***	1.174***	1.16***	1.014***	1.042***	1.104***	1.107***	0.898***	0.87***	1.091***	1.116***	1.029***	1.02***	1.107***	1.189***
Fruits	-0.889	-0.597	0.201	-0.001	0.229	0.324	0.392	0.487***	0.269	-0.083	0.031	-0.021	-0.849***	-0.645	-0.12	-0.305	-0.07	-0.035	-0.134	-0.073
Vegetables	0.182	0.006	-1.176***	-1.176***	-0.343	-0.237	-0.151	-0.059	0.454***	0.44***	-0.148	-0.26	0.193	0.272	0.149	0.085	-0.094	-0.098	-0.04	0.06
Beef, chicken and pork products	0.407	0.605	-0.699	-0.549	-0.271	-1.239	-0.018	-0.246	0.128	-0.242	-0.265	0.37	-0.226	0.117	-0.141	0.318	0.083	-0.017	-0.045	-0.231
Fish and shellfish	2.029	2.39***	-0.891	-0.374	-0.064	-0.628	-1.94***	-1.938***	-0.248	-0.092	0.087	-0.744	1.447	0.998	-0.164	0.336	-0.286	0.051	-1.145	-1.159
Milk, yogurt and dairy products	0.526	-0.188	0.964	0.955***	0.141	-0.244	-0.088	-0.033	-1.059	-1.88***	-0.017	0.055	-0.658	0.064	-0.444	-0.15	0.262	0.422	-0.641	-0.043
Eggs and cheese	0.08	-0.1	-0.591	-0.953	-0.513	0.606	0.062	-0.477	-0.04	0.08	-1.278	-0.428	-0.209	-1.036	0.498	0.72	-0.055	-0.262	0.942	0.742
Tortilla, rice, cereals and pasta	-1.185***	-0.839	0.305	0.403	-0.154	0.102	0.394	0.276	-0.446	0.058	-0.07	-0.413	-0.254	-0.906	0.191	0.09	0.112	0.082	0.211	0.278
Bread and pizza	-0.341	-0.913	0.385	0.227	-0.201	0.467	-0.077	0.196	-0.58	-0.218	0.36	0.645	0.325	0.16	-0.467	-1.087***	-0.201	-0.051	-0.296	-0.542
Seasonings	-0.438	-0.19	-0.616	-0.563	0.268	-0.036	-0.321	0.057	0.782	1.052	-0.089	-0.41	0.462	0.293	-0.462	-0.083	-0.495	-0.805	-0.12	-0.335
Desserts	-0.567	-0.314	-0.2	0.181	-0.104	-0.434	-0.866	-0.847	-1.289	-0.091	1.055	0.836	0.575	0.716	-0.46	-0.688	-0.082	-0.246	0.833	-0.362

* Estimations without demographic variables.

Fig. 4. Value of Food Waste & Uncompensated Elasticities (before and during Covid-19).

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