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Retail prices for sustainable, healthy diets: are foods with lower environmental impacts and healthier nutritional profiles also more expensive?

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Copyright 2023 by Elena M. Martinez, Nicole T. Blackstone, Parke E. Wilde, and William A. Masters. All rights reserved. Readers may make verbatim copies of this document for non-commercial purposes by any means, provided this copyright notice appears on all such copies. 1 Abstract

3 Background 4 Affordability is a key barrier to shifting to healthier, more environmentally sustainable diets. 5 Nutrient-dense foods are more expensive for meeting daily energy needs compared to less 6 healthy food groups, and some strategies for reducing environmental impacts of food systems 7 can increase food prices. Still, healthy, environmentally sustainable diets may be less expensive 8 in some contexts. We provide the first global test of how food prices relate to the 9 environmental impacts and nutritional value of food items within and between food groups. 10 11 Methods 12 We use retail food prices from the World Bank International Comparison Program (ICP) from 13 181 countries in 2011 and 2017. We match ICP food items to estimates of GHG emissions, water footprint, and nutritional profile from published research. We use visualizations and OLS 14 15 regression to estimate the relationship between prices per kilocalorie and GHG emissions, 16 water footprint, and nutrient profile of retail food items. 17 18 Findings 19 We find food items with lower emissions and water footprint are less expensive ways to meet 20 dietary needs in all food groups, with large heterogeneity between food groups. Food items

- 21 with healthier nutritional profile are significantly more expensive in most but not all food
- 22 groups, and different aspects of healthfulness drive this association for different food groups.

23	Price per kilocalorie is most strongly associated with environmental impacts and nutritional
24	profile for animal source foods, where a 50% increase in price per kilocalorie is associated with
25	an 8.7 gram CO ₂ -equivalent per 100 kilocalories increase in GHG emissions, 19.7 liter per 100
26	kilocalorie increase in water footprint, and 4.0 point increase in Food Compass Score.
27	
28	Interpretation
29	Less expensive food items tend to have lower environmental impacts but also lower nutritional
30	profiles. Still, there are inexpensive, low-impact options within each food group. Accounting for
31	these differences in environmental harm, health impacts and cost by type of food could help
32	guide policy interventions towards healthier and more environmentally sustainable options for
33	all.
34	
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37	Prices for Nutrition project (INV-016158).

39 Introduction

40 Food systems have significant impacts on the health of our planet, contributing to 41 environmental crises including climate change, water scarcity, biodiversity loss, and pollution. 42 Food systems account for as much as one third of anthropogenic greenhouse gas (GHG) 43 emissions (Crippa et al. 2021) and 70 percent of freshwater withdrawals (FAO 2021), as well as 44 about 32 percent of terrestrial acidification and 78 percent of aquatic eutrophication (Poore 45 and Nemecek 2018). At the same time, inadequate and poor-quality diets contribute to hunger, 46 food insecurity, and rising prevalence of diet-related chronic diseases, while also exacerbating 47 environmental crises (Willett et al. 2019; FAO et al. 2022; Clark et al. 2019). 48 Many have called for shifts towards healthier, more environmentally sustainable diets 49 to address these challenges (Tilman and Clark 2014; Willett et al. 2019). However, food prices 50 are a key barrier to consuming healthy, sustainable diets for many people. For people to shift 51 their food choices, healthy, environmentally sustainable foods must be affordable, yet healthy 52 diets remain unaffordable for over three billion of people globally (FAO et al. 2022). 53 Analyses of agricultural and food policy often assume, either implicitly or explicitly, that 54 more environmentally sustainable and healthier diets are more expensive for consumers (FAO 55 et al. 2022; Willett et al. 2019; Lindgren et al. 2018). Narratives about the cost of healthy, 56 environmentally sustainable foods are partially driven by consumers' perceptions. Many 57 consumers are willing to pay a premium for products marketed with health or sustainability claims, which may drive both beliefs about the relative prices of these products (Dolgopolova 58 59 and Teuber 2018; Alsubhi et al. 2023; S. Li and Kallas 2021) and the higher prices often charged

for them (J. Li and Hooker 2009), which consumers may extrapolate to the mistaken belief that
all healthier foods are more expensive (Haws, Reczek, and Sample 2017).

62 Many past studies on the relationship between food price and environmental impacts of 63 food systems have focused on trade-offs between reducing environmental impacts of food 64 systems and improving food security and diets. For instance, evidence from modelling studies 65 indicates that land-based strategies to mitigate GHG emissions (e.g., reducing land use change to protect forested land, growing crops for bioenergy, or switching to climate-smart production 66 67 practices) can increase land scarcity and production costs, thus increasing food prices (Stevanović et al. 2017; Fujimori et al. 2022; Doelman et al. 2019). Policies that aim to improve 68 69 the sustainability of groundwater use are also predicted to reduce total agricultural production, 70 thus increasing food prices (Calzadilla, Rehdanz, and Tol 2010).

There can also be trade-offs between the healthfulness and cost of foods. At retail food outlets, fruits, vegetables, and other nutrient-rich food groups are more expensive on average than starchy staples, vegetable oils, sugars, and other less healthy foods for meeting daily energy needs (Headey and Alderman 2019; Carlson and Frazão 2012). Evidence from Belgium, Mexico, and the United States also suggests that higher-quality diets that are closer to meeting dietary guidelines are more expensive per kilocalorie and per day (Vandevijvere et al. 2020;

77 Curi-Quinto et al. 2022; Conrad et al. 2021).

When we consider both the healthfulness and environmental sustainability of foods and diets, the evidence is more mixed. The EAT-Lancet reference diet, a dietary pattern intended to be healthy for both people and the planet, is unaffordable for many, especially in lower-income countries (Hirvonen et al. 2020; Willett et al. 2019). Still, studies of modelled or observed diets 82 in specific countries show that some healthier, more environmentally sustainable dietary 83 patterns tend to be less expensive (Springmann et al. 2021; Curi-Quinto et al. 2022; Conrad et 84 al. 2023). Modelling global data, Springmann et al. (2021) suggest that vegetarian and vegan 85 diets are less expensive compared to current diets, especially in wealthier countries 86 (Springmann et al. 2021). Examining dietary surveys from Mexico, Curi-Quinto et al. (2022) 87 show that healthier, more environmentally sustainable diets are less expensive, and adults with 88 lower socioeconomic status are more likely to consume these diets (Curi-Quinto et al. 2022). 89 Analyzing the diets of individuals in the United States who follow popular dietary patterns, 90 Conrad et al. (2023) find that plant-based diets have low GHG emissions and relatively low cost, 91 yet there are trade-offs between cost, diet quality, and environmental impacts of other dietary 92 patterns (Conrad et al. 2023).

93 However, many of these theoretical dietary patterns differ markedly from what most 94 people currently consume and do not necessarily reflect the breadth of foods available at retail 95 food outlets globally (Hirvonen et al. 2020; Willett et al. 2019; Springmann et al. 2021). This 96 study provides the first global test of how market prices relate to the environmental impacts 97 and nutritional value of food items within and between food groups. We combine retail food 98 prices from 181 countries with estimates of the GHG emissions, water footprint, and nutritional 99 profile of these food items, to assess whether healthier, more environmentally sustainable 100 diets are more expensive. Identifying which healthier or more sustainable foods are actually 101 less expensive, within and between food groups, could help in the design of policy interventions 102 that achieve environmental and health goals at lower cost to consumers.

104 Methods

124

105 We use food item availability and retail prices from the World Bank's International 106 Comparison Program (ICP) global and regional food lists in 2011 and 2017. The ICP provides 107 average prices in local currency units (LCU) for 869 food items in 177 countries in 2011 and 732 108 food items in 175 countries in 2017, as reported by national statistical organizations (The World 109 Bank 2023). We convert to prices in 2017 United States dollars (USD) using purchasing power 110 parity (PPP) exchange rates for individual consumption expenditure by households, provided by 111 the ICP. We exclude 5 countries and territories (Anguilla, Bonaire, Cuba, Montserrat, and 112 Taiwan) for which PPP exchange rates were not available. 113 The ICP reports prices per reference quantity (e.g., 1 kilogram of rice, 500 grams of 114 bread, 1 liter of olive oil, etc.). We convert prices per reference quantity to prices per kilogram 115 using information available in food item descriptions provided by the ICP. We match the ICP 116 food items to food composition data - kilocalories per 100g and edible portion - from the USDA 117 Standard Reference Release 28 (SR-28), the USDA Food Products Database, the West Africa 118 Food Composition Table, the Bangladesh Food Composition Table, and the USDA Food Products 119 Database, and the FAO/INFOODS Global food composition database for fish and shellfish (uFish 120 1.0). We use food composition data to calculate prices per kilogram and per kilocalorie of edible 121 matter. (See equations in Appendix 1a.) 122 We classify food items into food groups based on the Healthy Diet Basket (HDB), a set of 123 globally comparable recommended intakes of six key food groups developed based on national

dietary guidelines from 10 countries. HDB food groups include starchy staples; animal-source

125 foods (ASFs); legumes, nuts and seeds; vegetables; fruits; and oils and fats (Herforth et al.

2022). We calculate prices per recommended daily intake by adjusting prices per kilocalorie of
edible matter by the HDB recommended intake of each food group. (See Appendix 1b for
recommended intakes of each HDB food group.) We categorize sugars, sweets, and candies into
an additional food group, for which there is no recommended intake. We exclude alcoholic
beverages, non-caloric beverages, coffee, tea, culinary ingredients, spices, herbs, condiments,
mixed dishes with unclear composition, and infant foods.

132 We draw estimates of greenhouse gas (GHG) emissions and water footprint of food 133 items from a database created by Petersson et al. (2021). GHG emissions estimates represent 134 all emissions from production and distribution of each food item; water footprint estimates 135 represent all water use and pollution from production and distribution of each food item, 136 including ground and surface water (blue water) and rain water (green water) (Harris et al. 137 2020). These estimates reflect environmental impacts of food items to the consumer stage, 138 including post farm gage impacts such as processing, packaging, and transport but excluding 139 post-market impacts such as cooking. This database includes estimates of GHG emissions in carbon dioxide equivalents (CO2e) per kilogram of food for 324 food items and estimates of 140 141 water footprint in liters of water per kilogram of food, based on the Global Water Footprint 142 Standard, for 320 food items. (See Appendix 1d for detailed methodology for matching GHG 143 emissions and water footprint estimates to ICP food items.) We convert GHG emissions to CO₂e 144 per kilocalorie of food and water footprint to liters per kilocalorie of food using food 145 composition data.

We estimate the nutritional profile of food items using established metrics, including
Food Compass Score (FCS) (Mozaffarian et al. 2021), Nutri-Score (Santé Publique France 2023),

148 and Health Star Rating (Australian Government 2023). FCS is a nutrient profiling system that 149 rates the healthfulness of foods on a scale of 0 to 100 based on 9 domains relevant to health 150 outcomes, including nutrient ratios (ratios of unsaturated to saturated fat, fiber to 151 carbohydrates, and/or potassium to sodium), vitamins, minerals, food-based ingredients, 152 additives, processing, specific lipids, total fiber and protein, and phytochemicals (Mozaffarian et 153 al. 2021). (See Appendix 1d for descriptions of the 9 FCS domains.) Nutri-Score, created by 154 Santé Publique France, is a nutritional rating between 0 and 5 based on the food item's content 155 per 100g of nutrients and foods to promote, including dietary fiber, protein, fruits, vegetables, 156 pulses, nuts, and plant oils, and nutrients to limit, including total sugar, saturated fat, sodium, 157 and total energy. The Nutri-Score is translated into a letter from A to E for use on a color-coded 158 front-of-pack label (Santé Publique France 2023). The Health Star Rating is a nutritional rating 159 that scores foods between 0.5 and 5 to inform front-of-pack food labels with 0.5 to 5 stars. 160 Health Star Ratings are based on the food item's total energy; content of nutrients associated 161 with chronic disease, including saturated fat, sodium, and sugar; and content of nutrients and 162 foods associated with improved health outcomes, including fiber, protein, fruits, vegetables, 163 nuts, and legumes (Australian Government 2023). We match the ICP food items to estimates of 164 the Health Star Ratings and Nutri-Score of USDA FNDDS 2015-16 food items from Mozaffarian 165 et al. (Mozaffarian et al. 2021) and to updated FCS of USDA FNDDS 2017-18 food items 166 provided by the Food Compass research team.

167 We visualize the relationship between GHG emissions, water footprint, and nutrient 168 profile and price per kilocalorie using scatter plots and line graphs. Due to the large number of 169 price observations, we use binned scatter plots, where each point represents the mean of the x-axis and y-axis variables across 100 equal-sized bins of the x-axis variable. Line graphs show
average GHG emissions, water footprint, and nutrient profile by decile of price per kilocalorie;
deciles represent deciles of price by food group, country, and year. We estimate the
associations between price per kilocalorie and GHG emissions, water footprint, and nutritional
profile using the following OLS regression model:

175

$$Y = \beta_0 + \beta_1 * \ln(price) + \varepsilon$$

176 Where Y is a vector of measures of environmental impacts and nutritional profiles of each ICP food item, including GHG emissions in kilograms of carbon dioxide-equivalents per kilocalorie of 177 178 food, water footprint in liters per kilocalorie of food, Food Compass Score on a scale from 0 to 179 100, each of the 9 component domains of FCS, Health Star Rating on a scale from 0 to 5, and 180 Nutri-Score on a scale from 1 to 5 (letter scores of E are converted to 1, D to 2, etc.), and price 181 is the price per kilocalorie of each ICP food item. Regression models include country fixed 182 effects and are stratified by HDB food group. Visualizations and analyses are executed in Stata 183 SE 16.

185 Results

We find that food items with lower emissions and water use are less expensive ways to meet dietary needs in all food groups, with large heterogeneity between food groups. Food items with healthier nutritional profile scores are significantly more expensive in most but not all food groups, and the relationship between price and nutritional profile varies between the different measures of healthfulness that make up the FCS.

191

192 GHG emissions and retail food prices

193 The GHG emissions associated with retail food items varies distinctly between food groups. ASFs have much higher GHG emissions per kilocalorie on average, and the most within-194 195 group variation in GHG emissions. Though some vegetables have lower GHG emissions, there is 196 a wide range of GHG emissions associated with different vegetables, including some high-197 emissions vegetables such as tomatoes and mushrooms that have higher GHG emissions than 198 inexpensive, low-emissions ASFs such as sardines and anchovies. 199 More expensive food items have significantly higher GHG emissions per kilocalorie for 200 all food groups except fruits (Figure 2). The magnitude of this association is largest for ASFs and 201 vegetables. A 50% increase in price per kilocalorie is associated with an increase in GHG 202 emissions of 8.659-grams CO₂-equivalent per 100 kilocalories for ASFs and 3.086-grams for 203 vegetables. In fact, the emissions associated with the most expensive of ASFs and vegetables in each country are over twice as high as the emissions associated with the cheapest foods in each 204 205 food group (Figure 3).

206	Starchy staples, legumes, nuts, and seeds, oils and fats, and sugars, sweets, and candies
207	have lower GHG emissions per kilocalorie compared to vegetables and ASFs across all deciles of
208	price per kilocalorie (Figure 3). Still, there is a smaller but significant association between price
209	and GHG emissions per kilocalorie in each of these food groups. A 50% increase in price per
210	kilocalorie is associated with an increase in GHG emissions of 1.634-grams CO_2 -equivalent per
211	100 kilocalories for sugars, sweets, and candies, a 0.115-gram increase for starchy staples, a
212	0.0845-gram increase for legumes, nuts, and seeds, and a 0.956-gram increase for oils and fats.
213	
214	Water footprint and retail food prices
215	There is wide variation in the magnitude of water footprint per kilocalorie between food
216	groups. On average, starchy staples, oils and fats, and sugars, sweets, and candies have the
217	lowest water footprint. In comparison, more nutrient-dense food groups, including animal-
218	sources foods, legumes, nuts, and seeds, fruits, and vegetables have higher water footprint and
219	larger variation in water footprint between food items within each food group (Figure 1b).
220	Retail food prices per kilocalorie are positively associated with water footprint for every
221	food group except for starchy staples (Figure 1b, Figure 2). The magnitude of association
222	between price and water footprint is largest for ASFs, followed by legumes, nuts, and seeds,
223	and vegetables. On average a 50% increase in price per kilocalorie is associated with a 19.659-
224	liter higher water footprint per 100 kilocalories for ASFs, an 18.157-liter increase for legumes,
225	nuts, and seeds, and a 13.042-liter increase for vegetables. Though fruits have relatively high
226	water footprint on average, the association between price and water footprint is slightly

smaller; a 50% increase in price per kilocalorie is associated with a 4.394-liter higher water
footprint (Figure 2).

229 For ASFs, the direction of the relationship between price and water footprint varies 230 somewhat as price increases (Figure 1b, Figure 3). While some relatively expensive ASFs have 231 high water footprint, such as fresh and cured beef products, some of the most expensive ASFs 232 in each country have comparatively low water footprint, such as certain cheeses and fresh fish 233 fillets. For vegetables, fruits, and legumes, nuts and seeds, the relationship between price per 234 kilocalorie and water footprint is somewhat more even across deciles of price (Figure 3). More 235 expensive food items within each food group generally have higher water footprint compared 236 to less expensive alternatives.

237

238 Nutrient profile and retail food prices

239 There is wide variation in nutrient profile between food groups. For most food groups, 240 price is positively associated with healthfulness, and the magnitude of this association is largest 241 for ASFs, followed by sugars, sweets, and candies, starchy staples, and vegetables. In contrast, 242 higher price is associated with lower healthfulness for oils and fats (Figure 1c, Figure 2). 243 Vegetables, fruits, and legumes, nuts, and seeds have high nutrient profile across all 244 deciles of price per kilocalorie (Figure 3). There is a small but significant positive association 245 between price and nutrient profile for these three food groups, though the magnitude of this 246 association is relatively small (Figure 2). A 50% increase in price per kilocalorie is associated 247 with a 1.551-point increase in FCS for vegetables, a 1.186-point increase for fruits, and a 0.363-248 point increase for legumes, nuts, and seeds, all relatively small on a scale from 0 to 100.

Starchy staples and sugars, sweets, and candies have lower nutrient profile on average across all deciles of price per kilocalorie, though more expensive options within each group do tend to be more nutritious (Figure 1c, Figure 3). Still, there is a small but significant positive association between price and nutrient profile for these food groups. A 50% increase in price per kilocalorie is associated with a 1.925-point increase in FCS for starchy staples and a 2.080point increase for sugars, sweets, and candies.

Higher price is most strongly associated with higher nutrient profile for ASFs. A 50%
increase in price per kilocalorie of ASFs is associated with a 4.049-point increase in FCS.
However, much of this association is driven by a smaller set of highly nutritious ASFs that are
expensive in many countries, including fresh fish like grouper, snapper, and sole (Figure 1c,
Figure 3).

The price per kilocalorie of oils and fats is negatively associated with nutrient profile. A
50% increase in the price of oils and fats is associated with a 7.879-point decrease in FCS. This
trend is primarily driven by the high cost of butter, ghee, and margarine in many countries,
which have much lower nutrient profile than comparatively inexpensive plant oils.
Results comparing other measures of nutrient profile, including Health Star Rating and
Nutri-Score to food prices per kilocalorie, are generally consistent with results on Food
Compass Score (see Appendices).

267

268 Domains of nutrient profile and retail food prices

269 FCS is a composite score calculated from sub-scores across 9 domains – nutrient ratios,
270 vitamins, minerals, food-based ingredients, additives, processing, specific lipids, fiber and

271 protein, and phytochemicals. When we look at the associations between price per kilocalorie 272 and each domain of the FCS, we see that certain domains are more strongly associated with 273 price in general, and certain domains drive associations with price for different food groups. In 274 general, the presence of food-based ingredients with proven links to chronic disease outcomes 275 and favorable nutrient ratios (i.e., unsaturated to saturated fat, fiber to carbohydrates, and 276 potassium to sodium) are most strongly associated with price per kilocalorie. Additives and 277 phytochemicals, however, are not strongly associated with price per kilocalorie for any food 278 group.

279 The associations between FCS and price also vary widely between domains. For 280 vegetables, higher cost is associated with higher content of minerals, vitamins, and fiber, 281 suggesting that less expensive vegetables are lower in these nutrients on average. In contrast, 282 these aspects of healthfulness are not associated with cost for fruits, suggesting that 283 inexpensive fruits are similarly high in minerals, vitamins, and fiber compared to less expensive 284 fruits. For legumes, nuts, and seeds, price is only significantly associated with favorable nutrient 285 ratios, again suggesting that the content of key nutrients such as minerals, vitamins, fiber, and 286 protein is similar across price points within this food group.

Among starchy staples and sugars, sweets, and candies, price per kilocalorie is most strongly associated with favorable nutrient ratios (fiber to carbohydrates and unsaturated to saturated fat, in this case). Thus, inexpensive, less healthful options within these food categories tend to be those high in refined grains, added sugars, and saturated fat. Higher cost of ASFs is most strongly associated with content of food-based ingredients. For ASFs, seafoods are given positive points towards food-based ingredients and red and

- 293 processed meats are given negative points, so this association is primarily driven by the high
- 294 cost of many seafoods, especially shellfish.

295 Discussion

315

296 Comparing retail food prices from 181 countries with estimates of the GHG emissions, 297 water footprint, and nutrient profile associated with each food item, we find that more 298 expensive retail food items tend to be more healthful and have higher environmental impacts. 299 Thus, less expensive foods tend to have lower environmental impacts but are somewhat less 300 nutritious compared to alternatives within the same food group. Higher price is associated with 301 higher GHG emissions in all food groups except for fruits, and the association between price and emissions is largest for ASFs and vegetables. Higher price is associated with higher water 302 303 footprint for all food groups except for starchy staples, and the association between price and water footprint is largest for nutrient-dense food groups including ASFs, legumes, nuts, and 304 305 seeds, vegetables, and fruits. Higher price is also associated with higher nutrient profile in all 306 food groups except oils and fats, though different aspects of healthfulness drive the association 307 with price in different food groups. Still, there are healthful, inexpensive options available in 308 each food group, and these options tend to have lower environmental impacts. While nutrient-309 dense food groups such as vegetables, fruits, and ASFs are more expensive on average per 310 kilocalorie compared to starchy staples, oils and fat, and sugars, there are less expensive, 311 relatively nutritious options within each of these food groups that also have lower 312 environmental impacts. 313 Past studies showing that healthier, more environmentally sustainable dietary patterns tend to be less expensive (Springmann et al. 2021; Curi-Quinto et al. 2022; Conrad et al. 2023) 314

316 and more fruits, vegetables, and plant-source protein foods. Our results are consistent with

have primarily focused on trade-offs between food groups, for example consuming less ASFs

these studies, reinforcing the finding that ASFs have both higher cost and higher environmental
impacts on average compared to other food groups. However, calls for broad dietary shifts are
often criticized as infeasible because of the difficulty of changing individual and cultural food
preferences and the high comparative cost of some nutrient-dense foods (Headey and
Alderman 2019).

322 We show that incentives aiming to lower environmental impacts of diets could instead 323 focus on shifts to less expensive, lower impact foods within each food group. This strategy 324 would be most effective for the nutrient-dense foods groups (ASFs, vegetables, fruits, and 325 legumes, nuts, and seeds) that already have the highest burden of cost and environmental 326 impacts, as well as the largest variation in cost and environmental impacts. Vegetables, fruits, 327 and legumes, nuts, and seeds have comparatively high nutrient profile at all price points, so 328 choosing less expensive options would have little impact on dietary quality. While the most 329 nutritious ASFs are also the most expensive, there are also nutrient-dense options at lower 330 price points.

331 For consumers to choose healthy, environmentally sustainable options within each food 332 group, however, they need access to information about these attributes. Our results highlight 333 the importance of creating comprehensive, standardized food labeling systems that convey 334 information about both the healthfulness and environmental impacts of foods. Some aspects of 335 nutrient profile are already communicated on food labels in many countries, though not often 336 in ways that are interpretable by consumers, and levels of environmental impact are rarely 337 shown on food labels. The database and methodology created in this study – linking retail food 338 items to prices, environmental impacts, and nutritional profiles – can be used to inform

comprehensive labeling schemes, as well as the selection of low-cost, healthy, environmentally
 sustainable foods for inclusion in nutrition programs or interventions.

These results can also highlight specific areas where innovations to improve the efficiency of food supply chains and reduce food prices. For example, we find that less expensive vegetables have lower GHG emissions and water footprint but are also less nutritious. In particular, less expensive vegetables tend to have lower vitamin and mineral content. Thus, innovations to reduce the price and environmental impacts of expensive vegetables such as tomatoes, spinach, and broccoli could have benefits for both nutrition and the environment.

348

349 Strengths and limitations

350 This is the first global analysis connecting retail food prices to estimates of the 351 environmental impacts and healthfulness of foods available at retail around the world. We 352 utilize average country-level retail food prices from 181 countries from the ICP, an established 353 initiative managed by the World Bank to monitor and compare retail prices between countries. 354 We leverage a comprehensive, recently created database of GHG emissions and water footprint 355 associated with specific food items, created through a standardized methodology that 356 accounted for the quality and uncertainty of existing evidence (Petersson et al. 2021). We 357 estimate nutrient profile using FCS, a multidimensional nutrient profiling system that allows us 358 to assess both the overall healthfulness of each food item and components that contribute to 359 these scores. By starting with retail food availability and prices, we focus on the cost and 360 impacts of the foods available in retail food environmental worldwide rather than foods

361 consumed as part of theoretical dietary patterns. By converting prices and environmental
362 impacts to units per kilocalorie, we are able to meaningfully compare between different
363 options within the same food group that have different mass, water content, and inedible
364 portion.

365 This study has a few important limitations. First, we use estimates of GHG emissions and 366 water footprint compiled by Petersson et al. (2021) based on a review of available evidence. 367 Most studies estimating the GHG emissions and water footprint of foods are from higher-368 income countries, yet we utilize ICP food prices from 181 countries. Thus, we use global 369 estimates of GHG emissions and water footprint for each food item rather than country-specific 370 estimates. In addition, estimates of GHG emissions and water footprint were not available for 371 all ICP food items. We matched GHG emissions estimates to 78% of ICP food items and water 372 footprint estimates to 76% of ICP food items. We exclude foods for which no appropriate match 373 was available, including some processed foods for which available GHG emissions and water 374 footprint estimates did not account for important post farm gate impacts. (See Appendix 1c for 375 details on matching between ICP food items and environmental impact estimates.) 376 Water footprint is a consolidated indicator that includes both green and blue water use 377 and pollution. The estimates used do not differentiate between green and blue water use, nor 378 do they account for local water scarcity. Still, the water footprint estimates from Petersson et 379 al. (2021) provide a starting point for understanding the relationship between retail food prices 380 and water use. In addition, food systems have important environmental impact beyond GHG

381 emissions and water use, such as contributions to land use and land use conversion,

biodiversity loss, and pollution of land, air, and waterways. Reliable estimates of the magnitude

of how specific foods contribute to these impacts are scarce. Future studies of the
environmental impacts of food items that focus on a wider variety of countries, foods, and
types of environmental impacts could lead to useful insights on the relationship between food
prices and environmental impacts for specific foods, agricultural production systems and value
chains, geographies, and contexts.

388

389 Conclusions

390 As climate change and other environmental crises intensify and diets continue to 391 transition towards less healthy diets in many countries, we increasingly need to identify 392 strategies to reduce the health and environmental impacts of diets while simultaneously 393 addressing the affordability of healthy diets. When we look at retail food environments 394 globally, less expensive food items tend to have lower environmental impacts but also lower 395 nutritional profiles. Still, there are inexpensive, low-impact options within each food group. 396 Accounting for these differences in environmental harm, health impacts, and cost by type of 397 food could help guide policy interventions towards healthier and more environmentally 398 sustainable options for all.

400	References
401	
402	Alsubhi, Moosa, Miranda Blake, Tan Nguyen, Ishani Majmudar, Marj Moodie, and Jaithri
403	Ananthapavan. 2023. "Consumer Willingness to Pay for Healthier Food Products: A
404	Systematic Review." Obesity Reviews 24 (1): e13525. https://doi.org/10.1111/OBR.13525.
405	Australian Government. 2023. "Health Star Rating System." 2023.
406	http://www.healthstarrating.gov.au/internet/healthstarrating/publishing.nsf/content/ho
407	me.
408	Calzadilla, Alvaro, Katrin Rehdanz, and Richard S.J. Tol. 2010. "The Economic Impact of More
409	Sustainable Water Use in Agriculture: A Computable General Equilibrium Analysis." Journal
410	of Hydrology 384 (3–4): 292–305. https://doi.org/10.1016/J.JHYDROL.2009.12.012.
411	Carlson, Andrea, and Elizabeth Frazão. 2012. "Are Healthy Foods Really More Expensive? It
412	Depends on How You Measure Price." 96. Economic Information Bulletin. Washington, DC.
413	https://www.ers.usda.gov/publications/pub-details/?pubid=44679.
414	Clark, Michael A., Marco Springmann, Jason Hill, and David Tilman. 2019. "Multiple Health and
415	Environmental Impacts of Foods." Proceedings of the National Academy of Sciences of the
416	United States of America 116 (46): 23357–62.
417	https://doi.org/10.1073/PNAS.1906908116/SUPPL_FILE/PNAS.1906908116.SD01.XLSX.
418	Conrad, Zach, Adam Drewnowski, Martha A. Belury, and David C. Love. 2023. "Greenhouse Gas
419	Emissions, Cost, and Diet Quality of Specific Diet Patterns in the United States." The
420	American Journal of Clinical Nutrition, April.
421	https://doi.org/10.1016/J.AJCNUT.2023.04.018.
422	Conrad, Zach, Sarah Reinhardt, Rebecca Boehm, and Acree McDowell. 2021. "Higher-Diet
423	Quality Is Associated with Higher Diet Costs When Eating at Home and Away from Home:
424	National Health and Nutrition Examination Survey, 2005–2016." Public Health Nutrition 24
425	(15): 5047–57. https://doi.org/10.1017/S1368980021002810.
426	Crippa, M., E. Solazzo, D. Guizzardi, F. Monforti-Ferrario, F. N. Tubiello, and A. Leip. 2021. "Food
427	Systems Are Responsible for a Third of Global Anthropogenic GHG Emissions." Nature Food
428	2 (3): 198–209. https://doi.org/10.1038/s43016-021-00225-9.
429	Curi-Quinto, Katherine, Mishel Unar-Munguía, Sonia Rodríguez-Ramírez, Juan A. Rivera, Jessica
430	Fanzo, Walter Willett, and Elin Röös. 2022. "Sustainability of Diets in Mexico: Diet Quality,
431	Environmental Footprint, Diet Cost, and Sociodemographic Factors." Frontiers in Nutrition
432	9 (62): 855793–2015. https://doi.org/10.3389/FNUT.2022.855793/FULL.
433	Damerau, Kerstin, Katharina Waha, and Mario Herrero. 2019. "The Impact of Nutrient-Rich
434	Food Choices on Agricultural Water-Use Efficiency." Nature Sustainability 2019 2:3 2 (3):
435	233–41. https://doi.org/10.1038/s41893-019-0242-1.
436	Doelman, Jonathan C., Elke Stehfest, Andrzej Tabeau, and Hans van Meijl. 2019. "Making the
437	Paris Agreement Climate Targets Consistent with Food Security Objectives." Global Food
438	Security 23 (December): 93–103. https://doi.org/10.1016/J.GFS.2019.04.003.
439	Dolgopolova, Irina, and Ramona Teuber. 2018. "Consumers' Willingness to Pay for Health
440	Benetits in Food Products: A Meta-Analysis." Applied Economic Perspectives and Policy 40
441	(2): 333–52. https://doi.org/10.1093/AEPP/PPX036.
442	FAO. 2021. "The State of the World's Land and Water Resources for Food and Agriculture –
443	Systems at Breaking Point (SOLAW 2021)." The State of the World's Land and Water

- 444 *Resources for Food and Agriculture Systems at Breaking Point (SOLAW 2021).* Rome: FAO.
 445 https://doi.org/10.4060/CB7654EN.
- FAO, IFAD, UNICEF, WFP, and WHO. 2022. "The State of Food Security and Nutrition in the
 World 2022: Repurposing Food and Agricultural Policies to Make Healthy Diets More
 Affordable." Rome: FAO. https://doi.org/10.4060/CC0639EN.
- Fujimori, Shinichiro, Wenchao Wu, Jonathan Doelman, Stefan Frank, Jordan Hristov, Page Kyle,
 Ronald Sands, et al. 2022. "Land-Based Climate Change Mitigation Measures Can Affect
 Agricultural Markets and Food Security." *Nature Food 2022 3:2* 3 (2): 110–21.
- 452 https://doi.org/10.1038/s43016-022-00464-4.
- Harris, Francesca, Cami Moss, Edward J.M. Joy, Ruth Quinn, Pauline F.D. Scheelbeek, Alan D.
 Dangour, and Rosemary Green. 2020. "The Water Footprint of Diets: A Global Systematic
 Review and Meta-Analysis." *Advances in Nutrition* 11 (2): 375–86.
- 456 https://doi.org/10.1093/ADVANCES/NMZ091.
- Haws, Kelly L., Rebecca Walker Reczek, and Kevin L. Sample. 2017. "Healthy Diets Make Empty
 Wallets: The Healthy = Expensive Intuition." *Journal of Consumer Research* 43 (6): 992–
 1007. https://doi.org/10.1093/JCR/UCW078.
- Headey, Derek D., and Harold H. Alderman. 2019. "The Relative Caloric Prices of Healthy and
 Unhealthy Foods Differ Systematically across Income Levels and Continents." *The Journal*of Nutrition 149 (11): 2020–33. https://doi.org/10.1093/JN/NXZ158.
- Herforth, Anna, Aishwara Venkat, Yan Bai, Leah Costlow, Cindy Hollerman, and William A.
 Masters. 2022. "Methods and Options to Monitor the Cost and Affordability of a Healthy
 Diet Globally: Background Paper for The State of Food Security and Nutrition in the World
 2022." 22–03. FAO Agricultural Development Economics Working Paper. Rome.
 https://doi.org/10.4060/cc1169en.
- Hirvonen, Kalle, Yan Bai, Derek Headey, and William A. Masters. 2020. "Affordability of the
 EAT–Lancet Reference Diet: A Global Analysis." *The Lancet Global Health* 8 (1): e59–66.
 https://doi.org/10.1016/S2214-109X(19)30447-4.
- Li, Ji, and Neal H. Hooker. 2009. "Documenting Food Safety Claims and Their Influence on
 Product Prices." Agricultural and Resource Economics Review 38 (3): 311–23.
 https://doi.org/10.1017/S1068280500009564.
- 474 Li, Shanshan, and Zein Kallas. 2021. "Meta-Analysis of Consumers' Willingness to Pay for
 475 Sustainable Food Products." *Appetite* 163 (August): 105239.
- 476 https://doi.org/10.1016/J.APPET.2021.105239.
- Lindgren, Elisabet, Francesca Harris, Alan D. Dangour, Alexandros Gasparatos, Michikazu
 Hiramatsu, Firouzeh Javadi, Brent Loken, Takahiro Murakami, Pauline Scheelbeek, and
 Andy Haines. 2018. "Sustainable Food Systems—a Health Perspective." Sustainability
- 480 *Science* 13 (6): 1505–17. https://doi.org/10.1007/S11625-018-0586-X/FIGURES/2.
- 481 Mozaffarian, Dariush, Naglaa H. El-Abbadi, Meghan O'Hearn, Josh Erndt-Marino, William A.
- 482 Masters, Paul Jacques, Peilin Shi, Jeffrey B. Blumberg, and Renata Micha. 2021. "Food
 483 Compass Is a Nutrient Profiling System Using Expanded Characteristics for Assessing
 484 Healthfulness of Foods." *Nature Food* 2 (10): 809–18. https://doi.org/10.1038/s43016-021-
- 485 00381-y.
- 486 Petersson, Tashina, Luca Secondi, Andrea Magnani, Marta Antonelli, Katarzyna Dembska,
- 487 Riccardo Valentini, Alessandra Varotto, and Simona Castaldi. 2021. "A Multilevel Carbon

- 488 and Water Footprint Dataset of Food Commodities." *Scientific Data 2021 8:1* 8 (1): 1–12.
 489 https://doi.org/10.1038/s41597-021-00909-8.
- 490 Poore, J., and T. Nemecek. 2018. "Reducing Food's Environmental Impacts through Producers 491 and Consumers." *Science* 360 (6392): 987–92. https://doi.org/10.1126/science.aaq0216.
- 491 and Consumers. Science 360 (6392): 987–92. https://doi.org/10.1126/science.aaqu216
- 492 Santé Publique France. 2023. "Nutri-Score." April 23, 2023.
 493 https://www.santepubliquefrance.fr/en/nutri-score.
- 493 https://www.santepubliquefrance.fr/en/nutri-score.
 494 Springmann, Marco, Michael A. Clark, Mike Rayner, Peter Scarborough, and Patrick Webb.
- 495 2021. "The Global and Regional Costs of Healthy and Sustainable Dietary Patterns: A
- 496 Modelling Study." *The Lancet Planetary Health* 5 (11): e797–807.
- 497 https://doi.org/10.1016/S2542-5196(21)00251-5.
- 498 Stevanović, Miodrag, Alexander Popp, Benjamin Leon Bodirsky, Florian Humpenöder, Christoph 499 Müller, Isabelle Weindl, Jan Philipp Dietrich, et al. 2017. "Mitigation Strategies for
- 500 Greenhouse Gas Emissions from Agriculture and Land-Use Change: Consequences for Food 501 Prices." Environmental Science and Technology 51 (1): 365–74.
- 502 https://doi.org/10.1021/ACS.EST.6B04291/ASSET/IMAGES/LARGE/ES-2016-
- 503 042913_0003.JPEG.
- 504 The World Bank. 2023. "International Comparison Program (ICP)." 2023.
- 505 https://www.worldbank.org/en/programs/icp.
- Tilman, David, and Michael Clark. 2014. "Global Diets Link Environmental Sustainability and
 Human Health." *Nature 2014 515:7528* 515 (7528): 518–22.
- 508 https://doi.org/10.1038/nature13959.
- 509 Vandevijvere, Stefanie, Michelle Seck, Camille Pedroni, Karin De Ridder, and Katia Castetbon.
- 510 2020. "Food Cost and Adherence to Guidelines for Healthy Diets: Evidence from Belgium."
- 511 *European Journal of Clinical Nutrition 2020 75:7* 75 (7): 1142–51.
- 512 https://doi.org/10.1038/s41430-020-00815-z.
- 513 Willett, Walter, Johan Rockström, Brent Loken, Marco Springmann, Tim Lang, Sonja Vermeulen,
- 514 Tara Garnett, et al. 2019. "Food in the Anthropocene: The EAT–Lancet Commission on
- 515 Healthy Diets from Sustainable Food Systems." *The Lancet*. Lancet Publishing Group.
- 516 https://doi.org/10.1016/S0140-6736(18)31788-4.
- 517

- 518 Tables and figures
- 519

520 Figure 1a. Estimated mean GHG emissions conditional on price per kilocalorie, by food group



521

522 Note: GHG emissions estimates from Petersson et al. (2021) matched to average retail food

523 prices from the World Bank International Comparison Program in 2011 and 2017 for 699 food

524 items in 181 countries. Price in 2017 USD per kilocalorie is shown in natural-log scale.





527

- 528 Note: Water footprint estimates from Petersson et al. (2021) matched to average retail food
- 529 prices from the World Bank International Comparison Program in 2011 and 2017 for 681 food
- 530 items in 181 countries. Price in 2017 USD per kilocalorie is shown in natural-log scale.

Figure 1c. Estimated mean Food Compass Score conditional on price per kilocalorie, by food group



534

535 Note: Food Compass Score calculations from Mozaffarian et al. (2021) matched to average

retail food prices from the World Bank International Comparison Program in 2011 and 2017 for

537 824 food items in 181 countries. Price in 2017 USD per kilocalorie is shown in natural-log scale.

Figure 2. Associations between price per kilocalorie and GHG emissions, water footprint, and Food Compass Score by food group



541

542 Note: Tick marks represent coefficients and 95% confidence intervals of linear regressions of

543 GHG emissions, water footprint, and Food Compass Score (FCS) on log(price) with country fixed

544 effects, stratified by food group. ASF stands for "animal-source foods."



Figure 3. GHG emissions, water footprint, and Food Compass Score by deciles of price per kilocalorie for each food group

Note: GHG emissions and water footprint estimates from Petersson et al. (2021) and Food

Deciles of price per kcal

Compass Score calculations from Mozaffarian et al. (2021) matched to average retail food

prices from the World Bank International Comparison Program in 2011 and 2017 for 824 food

items in 181 countries.

554 Figure 4. Associations between the 9 domains of Food Compass Score and price per

555 kilocalorie by food group



556

557 Note: Tick marks represent coefficients and 95% confidence intervals of linear regressions of

each domain of Food Compass Score (FCS) on log(price) with country fixed effects, stratified by

559 food group. Estimate for coefficient on "additives" omit the "oils & fats" food group because all

560 food items scored zero in this dimension. ASF stands for "animal-source foods."

562 Supplementary Materials

- 563
- 564 Appendix 1a. Equations for calculating price per kilogram (kg), kilocalorie (kcal), and
- 565 recommended daily intake
- 566
- 567 Appendix 2: Comparing retail food prices per kilogram and per recommended daily intake to
- 568 GHG emissions, water footprint, and nutritional profile
- 569
- 570 Appendix 3: Comparing retail food prices to nutritional profile using Health Star Rating and
- 571 Nutri-Score
- 572

573 574	Appendix 1. Supplementary methodological details
575	Appendix 1a. Equations for calculating price per kilogram (kg), kilocalorie (kcal), and
5/0 577	recommended daily intake of each food item
578	Price per kg of edible matter = $\frac{Price \ per \ kg}{Edible \ portion}$
579	
580	$Price \ per \ kcal \ of \ edible \ matter = \frac{Price \ per \ kg \ of \ edible \ matter}{Kcal \ per \ kg \ of \ food}$
581	
582	Price per recommended daily intake
583	= (Price per kcal of edible matter)
584	× (Recommended intake in kcal of food group)
585	

586 Appendix 1b. Healthy diet basket daily recommended intakes by food group

587

Food group	Minimum number of food items selected for cost of healthy diet	Total energy content (kcal)	Equivalent gram content, by reference food (edible portion)
Starchy staples	2	1160	322g dry rice
Animal-source foods	2	300	210g egg
Legumes, nuts, and	1	300	85g dry bean
seeds			
Vegetables	3	110	270-400g vegetable
Fruits	2	160	230-300g fruit
Oils and fats	1	300	34g oil

588 Source: Herforth et al., 2023

- 590 Appendix 1c: Environmental impact data sources and matching
- 591

592 ICP food items were matched to food item names in Petersson et al. (2021). Where 593 possible, ICP names were matched directly to names used by Petersson. If a direct match to the 594 food item was not available, we matched to estimates of GHG emissions and water footprint 595 for a group of foods (e.g., berries, seafood), referred to as typology or sub-typology by 596 Petersson et al. (For example, a food item "raspberries" might fit in the typology "fruits" and 597 the subtypology "berries.") For example, shrimp and prawns were matched directly to an 598 estimate of GHG emissions for shrimp and prawns, while crab was matched to an estimate of 599 GHG emission for seafood on average. ICP food items were excluded from the analysis if there 600 was no relevant food item, typology, or subtypology in Petersson et al. (e.g., camel meat) or if 601 the relevant typology or subtypology did not account for important ingredients or value chain 602 stages. For example, dried fish, smoked fish, and canned fish other than tuna were excluded 603 because the Petersson et al. estimate of GHG emissions for processed fish included only 604 estimates for canned tuna and fish sticks.

- 605Petersson et al. included estimates of the certainty of each GHG emissions and water606footprint estimate, along with suggestions for whether to use the estimate at the item,
- 607 typology, or subtypology level. We followed the following rules to match food item, typology,
- and subtypology estimates to each food item.
- 609

Recommendation in Petersson et	Estimate used
al. (2021) uatabase	
"Ok item"	Food item
"Item matched typology" OR	Typology
"Better typology"	
"Better subtypology" or "Better	Subtypology
typology or subtypology"	
"Item or typology" or "Item or	Food item, if item estimate had low uncertainty;
typology or subtypology"	Typology or subtypology, if item estimate had high
	uncertainty

611 Appendix 1d. Description of the 9 Food Compass Score domains

612

Domain	Description
Nutrient ratios	Ratios of the quality of fats (unsaturated:saturated fats),
	carbohydrates (carbohydrate:fibre), and/or minerals
	(potassium:sodium)
Vitamins	Vitamins related to undernutrition and chronic diseases (e.g.,
	Vitamin A, thiamin)
Minerals	Minerals related to undernutrition and chronic diseases (e.g.,
	calcium, iron)
Food-based ingredients	Food groups with impacts on chronic diseases (e.g., fruits, whole
	grains)
Additives	Food additives with evidence of heath harms (e.g., nitrates,
	artificial sweeteners)
Processing	NOVA classification and other processing characteristics (e.g.,
	fermentation, frying) with health implications
Specific lipids	Lipids with evidence of health associations (e.g., trans fats,
	cholesterol)
Fiber and protein	Total fiber and total protein
Phytochemicals	Total flavonoids and total carotenoids

613 Source: Mozaffarian et al. (2021), Supplementary Table 3

- 615 Appendix 2: Comparing retail food prices per kilogram and per recommended daily intake to
- 616 **GHG emissions, water footprint, and nutritional profile**
- 617
- 618 Supplementary Figure 2a. Estimated mean GHG emissions conditional price per kilogram, by
- 619 food group



- 620
- 621 Note: GHG emissions estimates from Petersson et al. (2021) matched to average retail food
- 622 prices from the World Bank International Comparison Program in 2011 and 2017 for 700 food
- 623 items in 181 countries. Price in 2017 USD per kilogram is shown in natural-log scale.
- 624

Supplementary Figure 2b. Estimated mean GHG emissions conditional on price per recommended daily intake, by food group



627

628 Note: GHG emissions estimates from Petersson et al. (2021) matched to average retail food

629 prices from the World Bank International Comparison Program in 2011 and 2017 for 637 food

630 items in 181 countries. Price in 2017 USD per recommended daily intake is shown in natural-log

631 *scale*.



633 Supplementary Figure 2c. GHG emissions by decile of price per kilogram for each food group

634

- Note: GHG emissions estimates from Petersson et al. (2021) matched to average retail food
- 636 prices from the World Bank International Comparison Program in 2011 and 2017 for 700 food
- 637 *items in 181 countries.*

639 Supplementary Figure 2d. GHG emissions by decile of price per recommended daily intake for640 each food group



641

- 642 Note: GHG emissions estimates from Petersson et al. (2021) matched to average retail food
- 643 prices from the World Bank International Comparison Program in 2011 and 2017 for 637 food
- 644 *items in 181 countries.*

646 Supplementary Figure 2e. Associations between price per kilogram and GHG emissions, water



647 footprint, and Food Compass Score by food group

648

649 Note: Tick marks represent coefficients and 95% confidence intervals of linear regressions of

650 GHG emissions, water footprint, and Food Compass Score (FCS) on log(price) with country fixed

651 effects, stratified by food group. Estimates per recommended daily intake omit "sugars, sweets

652 & candies" because there is no recommended intake of this food group. ASF stands for "animal-

653 source foods."

Supplementary Figure 2f. Associations between price per recommended daily intake and GHG emissions, water footprint, and Food Compass Score by food group



657

658 Note: Tick marks represent coefficients and 95% confidence intervals of linear regressions of

659 GHG emissions, water footprint, and Food Compass Score (FCS) on log(price) with country fixed

660 effects, stratified by food group. Estimates per recommended daily intake omit "sugars, sweets

661 & candies" because there is no recommended intake of this food group. ASF stands for "animal-

662 source foods."

Supplementary Figure 2g. Estimated mean water footprint, conditional on price per kilogram, by food group



666

667 Note: Water footprint estimates from Petersson et al. (2021) matched to average retail food

668 prices from the World Bank International Comparison Program in 2011 and 2017 for 682 food

669 items in 181 countries. Price in 2017 USD per kilogram is shown in natural-log scale.

671 Supplementary Figure 2h. Estimated mean water footprint conditional on price per

672 recommended daily intake, by food group



673

674 Note: Water footprint estimates from Petersson et al. (2021) matched to average retail food

675 prices from the World Bank International Comparison Program in 2011 and 2017 for 633 food

676 items in 181 countries. Price in 2017 USD per recommended daily intake is shown in natural-log

677 *scale*.





680

- Note: Water footprint estimates from Petersson et al. (2021) matched to average retail food
- 682 prices from the World Bank International Comparison Program in 2011 and 2017 for 682 food
- 683 *items in 181 countries.*

Supplementary Figure 2j. Water footprint by decile of price per recommended daily intake for
 each food group



687

- 688 Note: Water footprint estimates from Petersson et al. (2021) matched to average retail food
- 689 prices from the World Bank International Comparison Program in 2011 and 2017 for 633 food

690 *items in 181 countries.*

692 Supplementary Figure 2k. Estimated mean Food Compass Score conditional on price per

693 kilogram, by food group



694

- 695 Note: Food Compass Score calculations from Mozaffarian et al. (2021) matched to average
- 696 retail food prices from the World Bank International Comparison Program in 2011 and 2017 for
- 697 827 food items in 181 countries.

Supplementary Figure 2I. Estimated mean Food Compass Score conditional on price per recommended daily intake, by food group





702 Note: Food Compass Score calculations from Mozaffarian et al. (2021) matched to average

retail food prices from the World Bank International Comparison Program in 2011 and 2017 for

704 720 food items in 181 countries.

706 Supplementary Figure 2m. Food Compass Score by decile of price per kilogram for each food 707 group



- 708 709 Note: Food Compass Score calculations from Mozaffarian et al. (2021) matched to average
- 710 retail food prices from the World Bank International Comparison Program in 2011 and 2017 for
- 711 827 food items in 181 countries.

713 Supplementary Figure 2n. Food Compass Score by decile of price per kilogram for each food 714 group



- 715 716 Note: Food Compass Score calculations from Mozaffarian et al. (2021) matched to average
- 717 retail food prices from the World Bank International Comparison Program in 2011 and 2017 for
- 720 food items in 181 countries. 718

- 720 Appendix 3: Comparing retail food prices to nutritional profile using Health Star Rating and
- 721 Nutri-Score
- 722
- 723 Supplementary Figure 3a. Estimated mean Health Star Rating conditional on price per
- 724 kilocalorie, by food group



- 725
- 726 Note: Health Star Rating calculations from Mozaffarian et al. (2021) matched to average retail
- food prices from the World Bank International Comparison Program in 2011 and 2017 for 817
- food items in 181 countries. Price in 2017 USD per kilocalorie is shown in natural-log scale.
- 729

730 Supplementary Figure 3b. Estimated mean Health Star Rating conditional on price per

731 kilogram, by food group



732

Note: Health Star Rating calculations from Mozaffarian et al. (2021) matched to average retail

734 food prices from the World Bank International Comparison Program in 2011 and 2017 for 818

food items in 181 countries. Price in 2017 USD per kilogram is shown in natural-log scale.

737 Supplementary Figure 3c. Estimated mean Health Star Rating conditional on price per

738 recommended daily intake, by food group



739

740 Note: Health Star Rating calculations from Mozaffarian et al. (2021) matched to average retail

food prices from the World Bank International Comparison Program in 2011 and 2017 for 715

food items in 181 countries. Price in 2017 USD per recommended daily intake is shown in

743 natural-log scale.

Supplementary Figure 3d. Estimated mean Nutri-Score conditional on price per kilocalorie, by food group



747

748 Note: Nutri-Score calculations from Mozaffarian et al. (2021) matched to average retail food

prices from the World Bank International Comparison Program in 2011 and 2017 for 817 food

750 *items in 181 countries. Price in 2017 USD per kilocalorie is shown in natural-log scale.*

Supplementary Figure 3e. Estimated mean Nutri-Score conditional on price per kilogram, by food group



754

Note: Nutri-Score calculations from Mozaffarian et al. (2021) matched to average retail food

prices from the World Bank International Comparison Program in 2011 and 2017 for 818 food

757 items in 181 countries. Price in 2017 USD per kilogram is shown in natural-log scale.

759 Supplementary Figure 3f. Estimated mean Nutri-Score conditional on price per recommended

760 daily intake, by food group



761

762 Note: Nutri-Score calculations from Mozaffarian et al. (2021) matched to average retail food

763 prices from the World Bank International Comparison Program in 2011 and 2017 for 818 food

764 items in 715 countries. Price in 2017 USD per recommended daily intake is shown in natural-log

765 scale.

Supplementary Figure 3g. Health Star Rating by deciles of price per kilocalorie, kilogram, and
 daily recommended intake for each food group



772 Note: Health Star Rating calculations from Mozaffarian et al. (2021) matched to average retail

food prices from the World Bank International Comparison Program in 2011 and 2017 for 818

food items in 181 countries.

769

770

Supplementary Figure 3h. Nutri-Score by deciles of price per kilocalorie, kilogram, and daily
 recommended intake for each food group



780 Note: Nutri-Score calculations from Mozaffarian et al. (2021) matched to average retail food

prices from the World Bank International Comparison Program in 2011 and 2017 for 818 food

782 *items in 181 countries.*

777

- 783 Supplementary Figure 3i. Associations between Health Star Rating and price per kilocalorie,
- 784 kilogram, and recommended daily intake by food group



785

786 Note: Tick marks represent coefficients and 95% confidence intervals of linear regressions of

787 Health Star Rating (HSR) on log(price) with country fixed effects, stratified by food group.

788 Estimates per recommended daily intake omit "sugars, sweets & candies" because there is no

789 recommended intake of this food group. ASF stands for "animal-source foods."

791 Supplementary Figure 3j. Associations between Nutri-Score and price per kilocalorie,





793

794 Note: Tick marks represent coefficients and 95% confidence intervals of linear regressions of

795 Nutri-Score on log(price) with country fixed effects, stratified by food group. Estimates per

recommended daily intake omit "sugars, sweets & candies" because there is no recommended

797 intake of this food group. ASF stands for "animal-source foods."