

The global seafood trade, embodied nutrients, and nutritional affordability

Received: 9 March 2023

Accepted: 9 June 2025

Published online: 01 July 2025

 Check for updates

Yaqin Liu¹, Martin D. Smith²✉, Joshua K. Abbott³, David Dietz⁴,
Dustin Colson Leaning², Adam Smyth⁵ & Tsugumi Yamashita⁶

Globalization of seafood markets raises concerns about nutritional insecurity, as developing countries export nutrient-dense seafood to developed countries. However, imported seafood may offset nutritional losses from exports. Developing countries import seafood with low prices relative to developed countries, raising questions of whether low-price imports provide less nutrition and contribute to nutritional insecurity. We construct a dataset connecting country-level seafood trade flows to product-specific data on nutrient concentrations to investigate how the seafood trade affects nutritional affordability. We compare nutrient density per dollar in imported seafood. Across three macronutrients and six micronutrients and using six distinct classifications of development status, we consistently find that developing countries pay lower prices for nutrition in imported seafood than developed countries. We show that the nutritional bargain for developing countries partly reflects differences in the non-nutritional characteristics of seafood imports between developed and developing countries, including the extent of processing and product form.

Seafood is a major contributor to global food security and provides critical macronutrients and micronutrients for human nutrition^{1–9}. Seafood, which includes aquatic foods from marine and freshwater environments, contributes over 15% of total animal protein consumption globally, and 3.3 billion people worldwide rely on seafood for at least 20% of their animal protein intake¹⁰. In developing countries, seafood can be one of the few accessible sources of key micronutrients and animal protein^{4–6}. Seafood is also the most internationally traded food group in the world, and this trade results in a modest net flow of seafood from developing countries to developed countries by volume¹¹. Nonetheless, developed countries as a group have a large seafood trade deficit measured in value because developing countries tend to export high-value seafood and import relatively low-value seafood¹². This value imbalance raises questions about whether this low-value seafood is less nutritionally dense than the healthy seafood exported by developing countries, such that seafood

trade may exacerbate the nutritional deficits of developing countries^{5,9}. Locally sourced fish in developing countries have higher micronutrient content than some major globally traded fish such as tilapia, suggesting that more nutritious fish could be displaced from diets through trade⁶. Moreover, at the country level, species composition is a more important determinant of nutrient content than total fishery yield⁵.

Studies find mixed results of the impacts of the seafood trade on development and nutritional security. For example, Béné, Lawton, and Allison¹³ use aggregate country-level data to show that the fish trade is neither positively nor negatively correlated with development outcomes for African countries. Nash et al.⁹ examine net nutrient gains and losses from reciprocal trade in wild-caught seafood, using country-level catch data. They use a statistical model that predicts nutrient content at the species level based on other species in the same family⁵. Nash et al.⁹ find that 63% of countries experience net gains in nutrients

¹Marine Policy Center, Woods Hole Oceanographic Institution, Woods Hole, MA, USA. ²Nicholas School of the Environment, Duke University, Durham, NC, USA. ³School of Sustainability, Arizona State University, Tempe, AZ, USA. ⁴Global Seafood Alliance, Portsmouth, NH, USA. ⁵Applied Ocean Physics and Engineering, Woods Hole Oceanographic Institution, Woods Hole, MA, USA. ⁶Department of Agricultural and Resource Economics, University of California, Davis, Davis, CA, USA. ✉ e-mail: martin.smith@duke.edu

through trade, but of the countries that experience net losses, half of them are small-island developing states and/or African nations. There is limited understanding of whether trade in farmed seafood exhibits similar patterns and the extent to which seafood processing mediates nutrient flows. In the broader food system, international trade increases macronutrient availability and access in low-income countries¹⁴. However, there is limited understanding of whether this finding holds within the seafood sector.

The literature on nutritional security also finds that food prices are an essential element of access to nutrition^{9,15,16}, but limited information exists linking seafood prices to nutrient content. Lower seafood prices could not only increase the availability of seafood-based nutrition but also displace less healthy red meat and other animal proteins⁸. Yet, concerns persist that globalized seafood markets may be driving up prices for low-income consumers, reducing nutrient accessibility^{15,17,18}. Higher prices potentially benefit fishers and fish traders at the expense of fish consumers^{18–20}. On the whole, global seafood prices have remained roughly constant over the past several decades^{21,22}, but there is limited understanding of how trade-driven differences in seafood prices between developed and developing countries have affected nutritional affordability.

To assess the impact of the global seafood trade on food and nutritional security, it is necessary to quantify the embodied nutrients in traded seafood products and evaluate the nutritional affordability of these products in developed and developing countries. This assessment presents four research challenges. First, quantifying nutrient density per dollar in traded seafood requires detailed information at the species level, as nutrient content varies widely across species⁵. Second, embodied nutrients vary by product form and degree of processing, such as a whole fish or a fillet of the same species. We have a limited understanding of the impacts of processing form—e.g., whole, filleted, or meat—on nutritional affordability despite considerable evidence showing that these attributes affect seafood pricing^{17,23–26}. In general, the nutritional content in seafood is bundled with other seafood product attributes that high-income consumers demand^{17,23–26}. As a result, the high degree of international trade in seafood raises the theoretical possibility that developing countries are outbid in the market for nutrients¹⁷. High-income consumers who are concentrated in developed countries may simply exhibit higher willingness to pay for nutritional attributes than their counterparts in developing countries. Alternatively, high-income consumers may inadvertently draw nutrition away from consumers in developing countries due to their higher valuations of other product attributes that are correlated with nutrition¹⁷. Third, assessing nutritional affordability requires an analysis of both wild-caught and farmed seafood. Farmed seafood is roughly half of global seafood supply¹⁰ and is an increasingly important component of global food security^{27–29}. While a large share of farmed seafood is consumed domestically, there is still substantial international trade^{29,30}. Moreover, farmed and wild-caught seafood markets are often highly integrated and jointly determine consumer prices^{19,31,32}. Fourth, testing hypotheses about nutritional affordability for developing countries requires an operational definition to distinguish between developing and developed countries. Because there are many ways to characterize development status of countries—including categories based on income per capita³³, food insecurity³⁴, specific geographies such as small island developing states⁹, and measures that combine standard of living with health, longevity, and knowledge³⁵—it is important to establish that results about nutritional affordability are robust across reasonable alternative definitions.

Here we analyze prices and nutritional content of internationally traded seafood and assess whether international trade is likely to enhance or erode nutritional affordability for developing countries. Importantly, we find that the global seafood trade may actually increase nutritional affordability for developing countries. To establish

this finding, we construct a database that links global trade data containing product information from both wild-caught and farmed seafood with a data set containing detailed nutritional information by fish species and product form. We analyze seafood import prices and nutrients using data from the top 41 exporting countries that together constitute 90% of the global seafood trade. The bilateral trades of these countries contain transactions with 237 unique importing countries and independent territories, 266 unique seafood products, and 267,505 total observations. Recognizing that there are competing definitions and cutoff points for distinguishing between developing and developed countries, we use six different ways of categorizing developed and developing countries (two based strictly on gross domestic product per capita, one using the United Nations Human Development Index, one based on Food and Agriculture Organization's list of Low-income Food Deficit Countries, and two using World Bank categories), and we compute nutrition per dollar for each of nine different nutrients (three macronutrients and six micronutrients). From here on, developed/developing refers to these alternative definitions, with the particular definition being clear from context. We consistently find that developing countries receive an overall discount on the nutrients analyzed. That is, developing countries receive more nutrition per dollar spent than developed countries. This result holds across all of the micronutrients and macronutrients that we analyze and is robust to the six different ways of dividing developed and developing countries, trimming the sample to exclude potential outliers, excluding observations from major re-exporting countries, and limiting the sample to products with exact one-to-one matches between the trade and nutrition databases. We find that the net exchange of high-value exports from developing countries for low-value imports does not reflect lower quality in the form of lower nutritional content; instead, a substantial portion of the value difference stems from non-nutritional attributes that differ across developed and developing country importers such as type of preservation and product form.

Results

Nutrition per dollar

Our main finding is that developing country importers pay lower prices for nutrition than developed country importers in the global seafood trade. For both macronutrients and micronutrients, and using our first categorization of developed/developing (Dev 1), developing countries receive more nutrition per dollar in seafood imports (Fig. 1, Supplementary Fig. 1). For macronutrients, pooling all years, we find that developing countries receive 55% more calories (Mann–Whitney $Z = 66.97$, $p < 0.0001$), 50% more protein (Mann–Whitney $Z = 64.96$, $p < 0.001$), and 66% more fatty acid content (Mann–Whitney $Z = 51.43$, $p < 0.001$) for the same expenditure compared to developed countries. For micronutrients, we find that developing countries receive 52% more vitamin B-12 (Mann–Whitney $Z = 63.59$, $p < 0.001$), 42% more calcium (Mann–Whitney $Z = 45.10$, $p < 0.001$), 55% more iron (Mann–Whitney $Z = 57.06$, $p < 0.001$), 43% more zinc (Mann–Whitney $Z = 56.54$, $p < 0.001$), 49% more potassium (Mann–Whitney $Z = 60.62$, $p < 0.001$), and 52% more magnesium (Mann–Whitney $Z = 66.10$, $p < 0.001$) for the same expenditure compared to developed countries (Supplementary Data 1). Our main finding also holds when analyzing individual years instead of pooling all years (Fig. 1, Supplementary Fig. 1a, Supplementary Data 1).

Qualitative results are the same when we consider alternative definitions for developed/developing countries (Dev 2, Dev 3, Dev 4, Dev 5, and Dev 6) (Supplementary Fig. 1b–f). Using our full sample, Mann–Whitney tests show that for each nutrient developing countries receive more nutrition per dollar for all classifications of development status (Supplementary Data 1). Results are consistent for parametric tests (t tests and volume-weighted t tests) with just a handful of counterexamples for individual nutrients in some years

(Supplementary Data 1). Results are also consistent when using trimmed or untrimmed data (See Methods; Supplementary Data 1).

As robustness checks, we assess the potential impact of the quality of match between the trade and nutrition data on our results. We specifically analyze the differences in nutrition per dollar based on two alternative matching criteria: 1) records for which there is an exact one-to-one species match and 2) records that exclude broad composite fish categories such as “Fish; fresh or chilled” and subjective matching to similar species, but include products in the trade data with multiple species listed. The first criterion is most restrictive because it only includes records from the trade data that indicate a single species. The second criterion is less restrictive in that it includes all of the one-to-one matches as well as multiple-to-one matches. Multiple-to-one matches exist because the trade data sometimes bundles multiple species in the same general market category. For instance, “Fish; Atlantic salmon and Danube salmon, frozen, excluding fillets, livers, roes and other fish meat of heading no. 0304” meets our second criterion because two species are listed. In this case, we match to the first species listed, Atlantic salmon. By contrast, “Fish; frozen, yellowfin tunas, excluding fillets, fish meat of 0304, and edible fish offal of subheadings 0303.91 to 0303.99,” meets our first criterion because there is a one-to-one match to yellowfin tuna in the nutrition data. Our main finding is robust to both of these exclusion criteria (Supplementary Fig. 2, Supplementary Data 2, 3).

As additional robustness checks, we analyzed restricted samples by excluding the importer being a major re-exporter. Re-exports

involve the export of foreign goods previously imported. In seafood markets, re-exports typically involve some added processing such as turning a whole fish into a fillet³⁶. By excluding re-exporters, we can rule out the possibility that our main finding is driven by processing margins in large re-exporting countries such as China. Our findings are qualitatively the same excluding re-exporters and quantitatively similar (Fig. 1, Supplementary Figs. 1, 2). The statistical tests on the restricted samples support our main finding and indicate that developing countries receive more nutrients per dollar than developed countries (Supplementary Data 1–3). We also re-run the Mann–Whitney tests on a dataset that pools all years and excludes transactions with China to address China’s particularly important role as an importer of seafood for re-export^{36,37} and to examine robustness when a large seafood trader in the middle of the income distribution is excluded. Our main findings are robust. Tests indicate that developing countries receive more nutrition per dollar than developed countries (Supplementary Data 1–3).

Nutrient levels per dollar are not strictly independent across different products, e.g., the amount of protein per dollar in a seafood product is positively correlated with the amount of vitamin B-12 per dollar (Supplementary Table 1). All nutrient per dollar measures are positively correlated with each other and statistically significant with some having substantially higher correlations than others (Supplementary Table 1). To examine the potential mediating effect of dependence across nutrients, we test our main result in a stacked model using Seemingly Unrelated Regression for each nutrient and

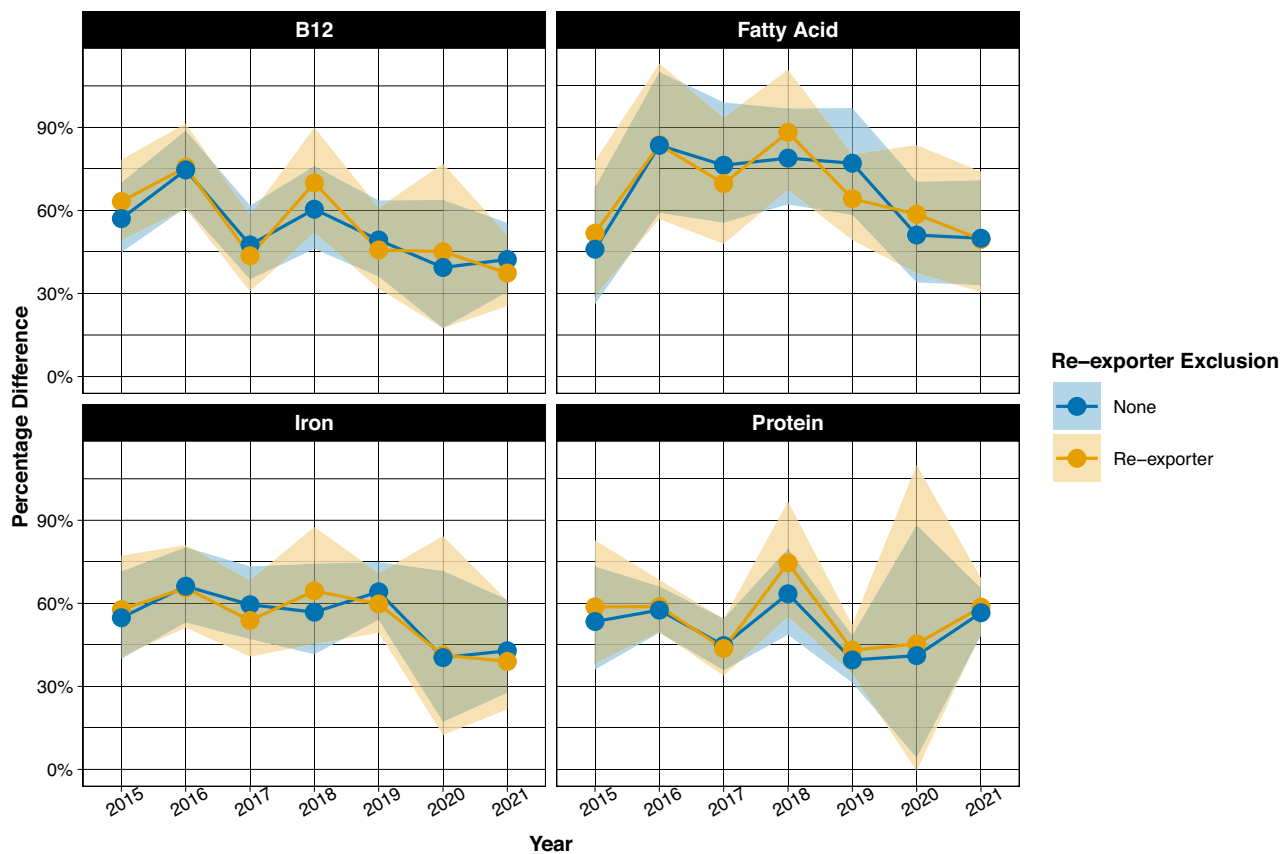


Fig. 1 | Developing countries pay lower prices for nutrition in the international seafood trade. Percent differences in nutrient concentration per dollar for developed and developing country importers for two macronutrients and two micronutrients. Positive percent differences imply that developing countries receive more nutrition per dollar. Point estimates (filled circles) and 95% confidence intervals (shaded areas) are depicted for each nutrient using the full sample for Dev 1, which divides Gross Domestic Product Per Capita in Purchasing Power Parity

(GDPPCPP) into quintiles, assigns the bottom two quintiles to developing, and assigns the top three quintiles to developed. Blue indicates the full sample. Orange excludes major re-exporters from the sample. Other nutrients and the remaining five development status distinctions show similar patterns, namely that developing country importers receive more nutrients per dollar than developed country importers (Supplementary Fig. 1). All differences are statistically different from zero based on Mann–Whitney tests (Supplementary Data 1).

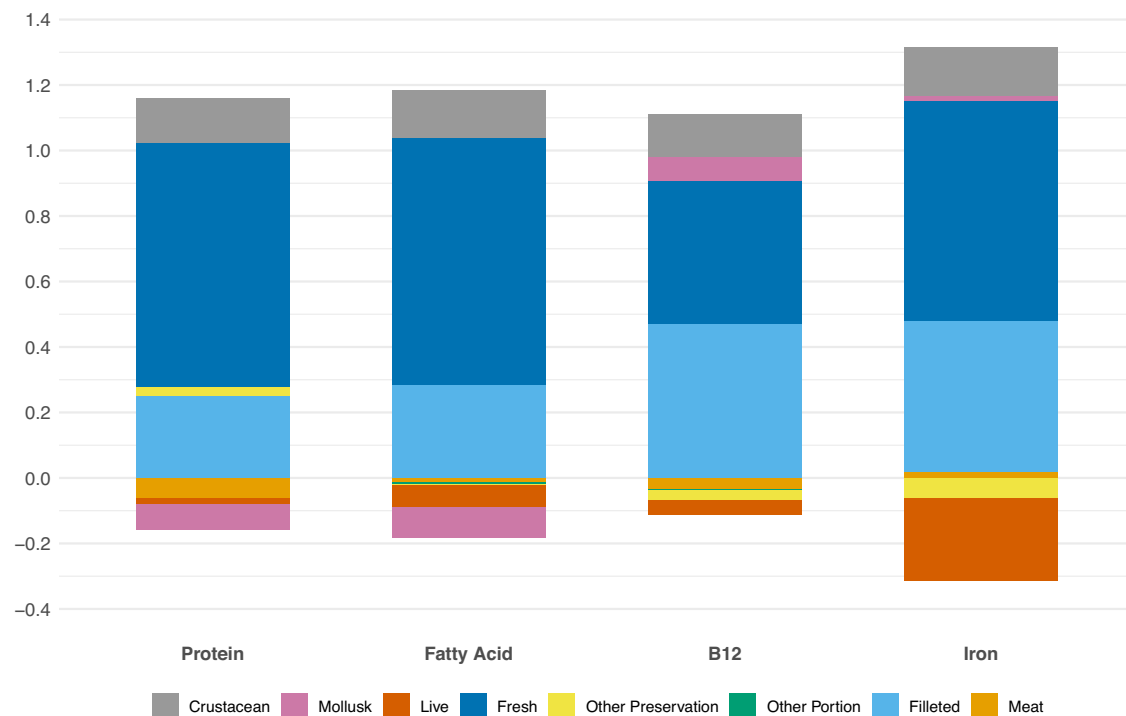


Fig. 2 | Contributions of product attributes to differences in nutrition per dollar. Normalized contributions to developed and developing differences in nutrient concentration per dollar for two macronutrients and two micronutrients based on Oaxaca-Blinder Decomposition using Dev 1. Dev 1 divides Gross Domestic Product Per Capita in Purchasing Power Parity (GDPPPPP) into quintiles, and it assigns the bottom two quintiles to developing and the top three quintiles to developed. Positive (negative) values reflect contributions to more (less) nutrient

content per dollar for developing countries. The base category is fish that is frozen and whole. The attribute contributions include crustacean (gray), mollusk (pink), live (dark orange), fresh (dark blue), other preservation (yellow), other portion (green), filleted (light blue), and meat (light orange). The attributes filleted and fresh are consistently associated with positive differences. Supplementary Fig. 3 depicts results for nine nutrients.

each developed/developing categorization (Supplementary Table 2). Our main finding is unchanged. Across all models and all nutrients, developing countries receive more nutrition per dollar than developed countries, we reject cross-equation restrictions of equal differences across the nutrients, and the percent differences are quantitatively similar to those found assuming independence across nutrients (Fig. 1, Supplementary Data 1, Supplementary Table 2).

Explaining differences in nutrition per dollar

The finding that developing countries systematically pay lower prices for nutrition naturally raises the question of what could explain these differences. A challenge in explaining developed/developing country differences is that consumers do not buy food nutrition directly but instead buy composite goods—e.g., a fresh cod fillet or a frozen whole anchovy. Each composite good has its own nutritional profile as well as a bundle of non-nutritional characteristics. Previous studies show consistent patterns for implicit prices of non-nutritional characteristics such as type of preservation (e.g., fresh or frozen) and product form (e.g., whole or filleted)^{23–26}. In particular, this literature consistently finds a price premium for fresh and filleted products relative to frozen and whole products, suggesting that these non-nutritional attributes may be a major driver of the robust gap in nutrition per dollar between developed and developing nations.

To assess this possibility, we estimate Oaxaca-Blinder decompositions for each nutrition per dollar variable. Results show that differences in product characteristics and market values of these characteristics explain differences in nutrition per dollar (Fig. 2, Supplementary Fig. 3). For both macronutrients and micronutrients, fresh and filleted consistently account for large shares of the explained variation from the Oaxaca-Blinder decompositions (Fig. 2, Supplementary Fig. 3).

The Oaxaca-Blinder decompositions also allow for statistical testing of explained variation (Tables 1 and 2). Each coefficient is the difference in each nutrient content per dollar between developed and developing countries explained by the product characteristic. We find that the attribute fresh contributes a statistically significant positive difference in nutrition per dollar for all development status indicators and for all nutrients tested (Table 1). Similarly, the attribute filleted contributes a statistically significant positive difference in nutrition per dollar for all development status indicators and for all nutrients tested (Table 2).

To understand these results, consider the equivalency in total nutrition for a fresh fish compared to a frozen one. While the nutrition is the same, the fresh fish is more expensive^{23–26}. That means fresh fish have lower nutrition per dollar (same nutrition but higher price) when holding other characteristics such as species constant. To the extent that developed countries tend to import more fresh fish relative to developing countries (as shown below), they receive less nutrition per dollar (positive difference in the Oaxaca-Blinder explained). Comparing these findings to recommended daily allowances also facilitates interpretation. Using the example of Dev 1 and protein, and pooling all years, the total difference between developing and developed is 15.23 g/\$ (Table 1). Using an RDA of 50 g³⁸, that constitutes 30.5% of the RDA. The difference explained by only the attribute fresh is 1.8 g/\$ (Table 1), or 3.6% of the RDA. For the micronutrient vitamin B-12, the percentages are even larger. The total difference between developing and developed is 3.83 mcg/\$ (Table 1). Using an RDA of 2.4 mcg³⁸, that constitutes 159.8% of the RDA. The difference explained by only the attribute fresh is 0.19 mcg/\$, or 7.9% of the RDA.

To evaluate the plausibility of the Oaxaca-Blinder findings, we directly test for differences in non-nutritional attributes of seafood

Table 1 | Explaining differences in nutrients per dollar using fresh

Units	Protein g/\$	Fatty acid g/\$	Calories kcal/\$	Calcium mg/\$	B12 mcg/\$	Iron mg/\$	Potassium mg/\$	Magnesium mg/\$	Zinc mg/\$
Dev 1									
Total difference	15.23	1.40	104.52	23.96	3.83	0.94	237.93	27.45	0.65
Fresh coefficient	1.80	0.16	11.65	1.08	0.19	0.09	27.52	3.01	0.02
Robust standard error	0.16	0.01	0.80	0.21	0.03	0.01	2.55	0.24	0.003
p-value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Dev 2									
Total difference	22.62	2.15	158.21	38.03	5.73	1.50	374.37	43.66	1.06
Fresh coefficient	2.44	0.23	16.42	1.41	0.32	0.13	37.38	4.17	0.03
Robust standard error	0.22	0.02	1.11	0.30	0.04	0.01	4.35	0.40	0.01
p-value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Dev 3									
Total difference	36.12	3.80	265.00	46.73	8.28	1.97	641.13	68.21	1.35
Fresh coefficient	2.40	0.21	15.58	1.46	0.26	0.12	36.76	4.02	0.03
Robust standard error	0.22	0.01	1.08	0.28	0.04	0.01	3.42	0.32	0.00
p-value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Dev 4									
Total difference	31.91	3.56	239.40	31.64	7.58	1.82	553.45	62.21	1.02
Fresh coefficient	2.66	0.23	17.24	1.57	0.27	0.14	40.67	4.44	0.03
Robust standard error	0.24	0.01	1.19	0.31	0.04	0.01	3.77	0.35	0.00
p-value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Dev 5									
Total difference	27.05	2.81	197.75	35.74	6.52	1.54	468.71	50.91	1.07
Fresh coefficient	2.42	0.21	15.67	1.46	0.26	0.13	37.00	4.04	0.03
Robust standard error	0.22	0.01	1.07	0.28	0.04	0.01	3.43	0.32	0.005
p-value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Dev 6									
Total difference	62.85	7.90	501.87	49.10	15.27	3.70	1118.94	130.68	1.77
Fresh coefficient	2.78	0.24	17.37	1.58	0.19	0.13	39.76	4.28	0.03
Robust standard error	0.47	0.02	2.26	0.50	0.07	0.02	6.61	0.62	0.01
p-value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Shows explained differences in fresh products from Oaxaca-Blinder regressions with robust standard errors and asymptotically normal Z tests. The coefficient is the difference in each nutrient content per dollar between developed and developing countries explained by the product characteristic. Dev 1 divides Gross Domestic Product Per Capita in Purchasing Power Parity (GDPPCPPP) into quintiles, and it assigns the bottom two quintiles to developing and the top three quintiles to developed; Dev 2 uses country-level GDPPCPPP and assigns the bottom two quintiles to developing, the top two quintiles to developed, and drops the middle quintile; Dev 3 divides the United Nations Human Development Index (HDI) into quartiles, assigns the first and second quartiles to developing and the third and fourth quartiles to developed; and Dev 4 uses the UN FAO's Low Income Food Deficit Country (LIFDC) list to assign developing, and countries not listed are considered developed; Dev 5 assigns a country to developing if the World Bank GNI indicator is in the bottom two groups (low or lower-middle income) and assigns all others to developed; Dev 6 assigns a country to developing if the World Bank GNI indicator is in the bottom group (low income), assigns the country to developed if it is in the top group (high income), and drops the other countries from the sample. The base category for preservation is frozen and whole.

product imported by developed and developing countries. Indeed, non-nutritional seafood attributes that are more highly valued in the market also tend to be more associated with developed country imports (Table 3). The shares of live, fresh, or other preservation are higher for developed country importers compared to developing country importers, whereas the share of frozen is lower (Table 3). Similarly, the share of filleted is higher for developed country importers compared to developing country importers, whereas the share of whole fish is lower (Table 3). These qualitative findings are robust to whether or not the transactions are volume weighted, but quantitatively the differences are larger when applying volume weights (Table 3). The findings are also consistent across all six development status indicators (Table 3, Supplementary Tables 3–7). These product characteristic differences provide supporting evidence that non-

nutritional attributes contribute to the differences in nutrients per dollar between developed and developing country importers.

As further supporting evidence that non-nutritional characteristics contribute to differences in nutrition per dollar for developed and developing countries, we run hedonic regressions that decompose price per kg into implicit prices for each product attribute. Consistent with previous hedonic studies of seafood markets^{23–26}, we find that fresh and filleted products are more highly valued than frozen and whole products (Table 4). The results are robust to including interactions with each of our six development status indicators (Table 4). These patterns of implicit prices, combined with covariate differences (Table 3, Supplementary Tables 3–7), suggest that discounts on nutrition to developing nations partially reflect observable differences in non-nutritional attributes of products imported by developed

Table 2 | Explaining differences in nutrients per dollar using filleted

Units	Protein g/\$	Fatty acid g/\$	Calories kcal/\$	Calcium mg/\$	B12 mcg/\$	Iron mg/\$	Potassium mg/\$	Magnesium mg/\$	Zinc mg/\$
Dev 1									
Total difference	15.23	1.40	104.52	23.96	3.83	0.94	237.93	27.45	0.65
Filleted coefficient	0.60	0.06	4.69	1.28	0.21	0.06	9.91	1.67	0.03
Robust standard error	0.04	0.00	0.29	0.10	0.01	0.00	0.74	0.09	0.001
p-value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Dev 2									
Total difference	22.62	2.15	158.21	38.03	5.73	1.50	374.37	43.66	1.06
Filleted coefficient	1.00	0.10	7.63	2.10	0.33	0.10	16.53	2.68	0.05
Robust standard error	0.07	0.01	0.45	0.16	0.01	0.00	1.25	0.14	0.002
p-value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Dev 3									
Total difference	36.12	3.80	265.00	46.73	8.28	1.97	641.13	68.21	1.35
Filleted coefficient	0.54	0.05	4.19	1.14	0.19	0.06	8.87	1.50	0.02
Robust standard error	0.05	0.00	0.39	0.12	0.02	0.00	0.90	0.13	0.002
p-value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Dev 4									
Total difference	31.91	3.56	239.40	31.64	7.58	1.82	553.45	62.21	1.02
Filleted coefficient	0.96	0.09	7.45	2.04	0.33	0.10	15.75	2.66	0.04
Robust standard error	0.07	0.01	0.48	0.16	0.02	0.01	1.20	0.16	0.002
p-value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Dev 5									
Total difference	27.05	2.81	197.75	35.74	6.52	1.54	468.71	50.91	1.07
Filleted coefficient	0.87	0.09	6.78	1.84	0.30	0.09	14.34	2.42	0.04
Robust standard error	0.06	0.00	0.39	0.13	0.01	0.00	1.03	0.13	0.002
p-value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Dev 6									
Total difference	62.85	7.90	501.87	49.10	15.27	3.70	1118.94	130.68	1.77
Filleted coefficient	0.32	0.03	2.57	0.65	0.12	0.03	4.97	0.88	0.01
Robust standard error	0.09	0.01	0.75	0.19	0.03	0.01	1.49	0.26	0.004
p-value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Shows explained differences in filleted products from Oaxaca-Blinder regressions with robust standard errors and asymptotically normal Z tests. The coefficient is the difference in each nutrient content per dollar between developed and developing countries explained by the product characteristic. Dev 1 divides Gross Domestic Product Per Capita in Purchasing Power Parity (GDPPCPPP) into quintiles, and it assigns the bottom two quintiles to developing and the top three quintiles to developed; Dev 2 uses country-level GDPPCPPP and assigns the bottom two quintiles to developing, the top two quintiles to developed, and drops the middle quintile; Dev 3 divides the United Nations Human Development Index (HDI) into quintiles, assigns the first and second quintiles to developing and the third and fourth quintiles to developed; and Dev 4 uses the UN FAO's Low Income Food Deficit Country (LIFDC) list to assign developing, and countries not listed are considered developed; Dev 5 assigns a country to developing if the World Bank GNI indicator is in the bottom two groups (low or lower-middle income) and assigns all others to developed; Dev 6 assigns a country to developing if the World Bank GNI indicator is in the bottom group (low income), assigns the country to developed if it is in the top group (high income), and drops the other countries from the sample. The base category for preservation is frozen and whole.

versus developing importers that are nonetheless bundled with nutritional attributes.

Discussion

We find that developing countries pay less for nutrition in seafood than developed countries. There is broad consensus that seafood plays an important nutritional role globally, and that role is even more pronounced in developing countries^{1–9}. There is a tendency for developed countries to attach a high value to fresh seafood, high-value product forms such as filleted, and crustaceans^{23–26}. These features add to an already elevated willingness to pay for seafood based on income. Our results suggest that because of this exchange, developing countries, which tend to be lower income, have access to seafood nutrition in imports at much lower prices. Understanding why some species and product forms are more highly valued than others in the global

seafood trade and whether these values are associated with embodied nutrient content is important future research.

Focusing on exports and the potential for developing countries to compromise nutritional security by trading away healthy seafood^{5,6} overlooks the potential gains on the other side of the market. That is, developing countries as importers gain access to low-price nutrition because many species and product forms are less valued in developed countries. In terms of quantity, some countries experience net increases of wild-caught seafood nutrition through reciprocal trade (63%), while others experience net losses⁹. The growing importance of aquaculture globally^{28,30,39}, which has previously been omitted from the seafood trade and nutrition literature, provides a potential channel through which reciprocal trade benefits even countries that experience net losses in wild-caught seafood nutrition. Our results, which include both wild-caught and farmed seafood, suggest another

Table 4 | Multivariate hedonic regressions of natural log of price per kilogram of fish imports

	(1) Baseline	(2) Dev1	(3) Dev2	(4) Dev3	(5) Dev4	(6) Dev5	(7) Dev6
Meat	0.246*** (0.0137)	0.159*** (0.0203)	0.133*** (0.0255)	0.0865 (0.0514)	-0.0175 (0.0317)	-0.0109 (0.0421)	0.161 (0.180)
Meat*Dev	-	0.155*** (0.0207)	0.213*** (0.0207)	0.152** (0.0539)	0.255*** (0.0261)	0.269*** (0.0439)	-0.00853 (0.174)
Fillet	0.617*** (0.0156)	0.552*** (0.0196)	0.596*** (0.0314)	0.656*** (0.0516)	0.650*** (0.0534)	0.600*** (0.0449)	0.686*** (0.0717)
Fillet*Dev	-	0.0988*** (0.0195)	0.0836** (0.0284)	-0.0581 (0.0462)	-0.0490 (0.0432)	-0.00116 (0.0395)	-0.198** (0.0627)
Other portion	0.676*** (0.0297)	0.657*** (0.0350)	0.627*** (0.0480)	0.528*** (0.142)	0.169 (0.172)	0.625*** (0.0838)	-0.873 (0.537)
Other portion *Dev	-	0.0658 (0.0416)	0.119** (0.0458)	0.165 (0.129)	0.531** (0.161)	0.0700 (0.0711)	1.507** (0.538)
Other preservation	0.549*** (0.0344)	0.487*** (0.0246)	0.423*** (0.0374)	0.143* (0.0722)	0.213*** (0.0520)	0.243*** (0.0529)	0.185** (0.0517)
Other preservation*Dev	-	0.147*** (0.0110)	0.232*** (0.0132)	0.452*** (0.0466)	0.360*** (0.0452)	0.356*** (0.0295)	0.361*** (0.0560)
Fresh	0.595*** (0.0222)	0.584*** (0.0145)	0.545*** (0.0205)	0.135** (0.0396)	0.176** (0.0597)	0.405*** (0.0418)	-0.337** (0.0975)
Fresh*Dev	-	0.0529* (0.0255)	0.126*** (0.0284)	0.509*** (0.0339)	0.444*** (0.0627)	0.228*** (0.0417)	0.847*** (0.0979)
Live	-0.0238 (0.0497)	0.0413 (0.0447)	0.0242 (0.0443)	0.280*** (0.0573)	0.232** (0.0732)	0.146*** (0.0373)	0.392** (0.143)
Live*Dev	-	-0.134*** (0.0244)	-0.137*** (0.0214)	-0.324*** (0.0605)	-0.256* (0.121)	-0.183** (0.0678)	-0.353* (0.171)
Mollusk	0.439*** (0.0763)	0.345*** (0.0813)	0.352*** (0.0765)	0.420*** (0.0506)	0.411*** (0.0808)	0.403*** (0.0641)	0.319** (0.0992)
Mollusk*Dev	-	0.197*** (0.0305)	0.219*** (0.0256)	0.00299 (0.0537)	0.0100 (0.0306)	0.0262 (0.0309)	0.0266 (0.0637)
Crustacean	1.098*** (0.0200)	1.060*** (0.0138)	1.022*** (0.0205)	0.809*** (0.0413)	0.982*** (0.0425)	0.931*** (0.0169)	0.896*** (0.0505)
Crustacean*Dev	-	0.0950*** (0.0238)	0.168*** (0.0330)	0.314*** (0.0296)	0.116* (0.0480)	0.193*** (0.0302)	0.118** (0.0384)
Constant	0.958*** (0.0236)	0.993*** (0.0198)	0.941*** (0.0227)	0.982*** (0.0218)	0.992*** (0.0213)	0.987*** (0.0210)	1.180*** (0.0179)
Observations	264,560	233,157	177,549	232,579	241,839	232,497	156,024
R-squared	0.185	0.194	0.200	0.197	0.191	0.194	0.176
Year FE	YES	YES	YES	YES	YES	YES	YES

The baseline model excludes interaction terms with development status. Dev 1 divides Gross Domestic Product Per Capita in Purchasing Power Parity (GDPPPPP) into quintiles, and it assigns the bottom two quintiles to developing and the top three quintiles to developed; Dev 2 uses country-level GDPPPPP and assigns the bottom two quintiles to developing, the top two quintiles to developed, and drops the middle quintile; Dev 3 divides the United Nations Human Development Index (HDI) into quartiles, assigns the first and second quartiles to developing and the third and fourth quartiles to developed; and Dev 4 uses the UN FAO's Low Income Food Deficit Country (LIFDC) list to assign developing, and countries not listed are considered developed; Dev 5 assigns a country to developing if the World Bank GNI indicator is in the bottom two groups (low or lower-middle income) and assigns all others to developed; Dev 6 assigns a country to developing if the World Bank GNI indicator is in the bottom group (low income), assigns the country to developed if it is in the top group (high income), and drops the other countries from the sample. The base categories are frozen for preservation, whole for portion, and developing country importer (DEV = 0). All models include year fixed effects. Robust standard errors are in parentheses and clustered at the year level, and ***indicates $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$. Filleted and fresh are positively valued relative to the base category in all specifications. Developed countries pay an extra premium relative to developing countries for fresh in all specifications.

Methods

Data

We construct a database by linking UN Comtrade⁵¹ with FAO's seafood nutrition database⁵². Comtrade contains bilateral international trade data that are finely resolved at the product level, while the FAO nutrition database contains species-level nutritional content for a wide range of macro- and micronutrients. The Comtrade data specifically includes: trade flow type (import vs. export), nation of import, nation of export, quantity, dollar value, and species or group of species traded. Additionally, Comtrade reports unique characteristics of each

product, such as fillet vs. whole, fresh vs. frozen, and other preparation types such as salted, dried, or smoked.

We begin to build the dataset by rank-ordering all countries based on 2019 seafood exports and selecting all countries that collectively constitute 90% of global seafood exports⁵³. This yields 41 countries: China, Norway, Russian Federation, Viet Nam, Peru, United States of America, Netherlands, Thailand, India, Chile, Indonesia, Spain, Denmark, Ecuador, Mauritania, Germany, Sweden, United Kingdom, Morocco, Taiwan Province of China, Iceland, Japan, Republic of Korea, Canada, Myanmar, Faroe Islands, Poland, Argentina, Namibia, France,

Mexico, Senegal, Malaysia, Ireland, New Zealand, Portugal, Oman, Pakistan, Türkiye, Philippines, and Greenland. We choose 2019 for the rank ordering as the last year prior to COVID-19.

We download all Comtrade data for these countries in the six-digit commodity codes HS030000 through HS030999 for the years 2015 through 2021, which includes all products listed as seafood in Comtrade. As Comtrade excludes all varieties of seaweed from this category, the analysis omits seaweed. Additionally, all products not directly consumed by humans are removed. This includes items directly labeled as “Not Fit for Human Consumption” or “Ornamental” as well as menhaden, krill, corals, and sponges. We also exclude fish-based flours. Other countries beyond our 41 exporting countries are well represented in the data through their relationships as import partners. The resulting dataset contains 267,505 total observations, 266 unique products, 237 unique importing countries and independent territories, and 1267 unique trading partner combinations.

The nutritional database is the FAO/INFOODS global food composition database for fish and shellfish, version 1.0 – uFish1.0⁵². The dataset includes “Food Name in English,” which we use to match to Comtrade; the percentage edible coefficient; and a wide range of nutrients summarized in amount per 100 g of edible seafood. For each of these individual product categories, the dataset affixes 181 unique nutritional components. This breakdown includes macronutrients such as calories, protein, and fatty acids, as well as micronutrients such as iron and calcium.

We link the Comtrade data to the nutritional data by using the full text description of each commodity code in Comtrade. Our matching protocol includes four match types (ordered from most to least precise): one-to-one exact match, multiple-to-one exact match, one-to-similar match, and composite goods.

One-to-one exact match ($n=91,635$). When possible, we directly match to the nutritional dataset with the same species (e.g. Atlantic cod) and same product form (e.g. fillet). If the species is available with complete nutritional information but not the same product form, we match the nutritional information with the species in the nutritional data having complete nutritional information. Then we choose another record in the nutritional dataset for the same species and product form to identify the edible coefficient. This allows us to use the edible coefficient for species and product form combinations when some of the nutritional information is missing from the FAO record. For cases in which edible coefficients are unavailable in the nutritional data, we assign the following values: 1.0 for fish meat, livers, roes, and smoked; 0.75 for fish fillets and salted or brined products; and 0.5 for whole fish. One-to-one exact matches are the highest quality matches, and we test our main results using only these records as the most restrictive dataset.

Multiple-to-one exact match ($n=96,796$). Often records in the Comtrade database report multiple species for the same commodity code. For a given trade, it is not specified what share of the trade consists of the individual species in the list. For these cases, we use the first species listed in Comtrade to match to FAO nutrition data. If that species is missing in FAO nutrition data, we go to the second in the list, and so forth. We follow the same rule as the one-to-one matching for the edible coefficient.

One-to-similar match ($n=20,634$). In some cases, the species in the Comtrade data is unavailable in the FAO nutrition data, or the Comtrade commodity code does not provide sufficient detail on the species. Here we choose a similar or representative species based on expert judgement of a species in a similar product category. The full list of these matches is as follows: bigeye tuna uses southern bluefin tuna; toothfish uses sea bass, mixed species; fish livers uses cod liver; frozen crabs uses blue crab; Nile perch uses snake head; fish fins (other than shark fins) uses shark fins; and we exclude fish, edible offal from the analysis. We follow the same rule as the one-to-one matching for the edible coefficient.

Composite goods ($n=58,440$). If the species is unspecified (denoted NSPF) in the Comtrade data, we create a composite species and weight the nutritional variables by the shares of the composite. We constructed weighted averages of the most frequently caught species within each category based on 2016 landings data and using species ranked highest in each category⁵³. Because landings for these broad categories are widely available for the United States, namely landings of different species of groundfish, flatfish, mollusk, and crustaceans, we use U.S. landings to create nutritional weights for composite goods. Within each grouping, the total quantity of landings was calculated, and each species contribution to that value was generated as a decimal proportion. These proportions acted as modifiers to a species’ nutritional value, and all values were summed to create a weighted-average nutritional profile. As fish and groundfish constitute much of the top landings by species, each of these used ten individual species to generate a nutritional profile. For flatfish, crustacean, and mollusks, species were only included that would have a noticeable effect on a nutritional profile, ranging from three to six species per category⁵⁴ (Supplementary Table 8). For several composites, we supplemented the FAO nutritional data with nutritional data from Japan’s Ministry of Education, Culture, Sports, Science, and Technology⁵⁵.

For our main set of tests – whether developing country seafood purchases are less nutritionally dense—we compute nutrition per dollar in each transaction by each nutrient. We define a transaction at the importer level so that trades between the trading partners of our 41 exporting countries are not double counted. To this end, we first compute total edible seafood in each transaction by multiplying the total quantity by the edible coefficient. We then create total nutrients for each macronutrient and micronutrient that we analyze. These include calories, protein, fatty acids, calcium, iron, magnesium, potassium, vitamin B-12, and zinc. We multiply each nutrient per 100 g by 10 to so that we have total nutrient content per kg of edible seafood and then multiply by total edible seafood to obtain total nutrients. We arrive at nutrition per dollar by dividing each total nutrient by the total dollar value of the transaction. Note that nutrition per dollar is the inverse of price. It is convenient to use the inverse of price because different nutrients are measured in different units such as grams of protein, kilocalories, milligrams of calcium, or micrograms of vitamin B-12. By using the inverse of price, we preserve the conventional scaling of different units for different nutrients.

For each transaction, we also link data for importing country gross domestic product per capita in purchasing power parity terms (GDPPCPPP)⁵⁶.

We categorize developing and developed six different ways: Dev 1 divides Gross Domestic Product Per Capita in Purchasing Power Parity (GDPPCPPP) into quintiles, and it assigns the bottom two quintiles to developing and the top three quintiles to developed; Dev 2 uses country-level GDPPCPPP and assigns the bottom two quintiles to developing, the top two quintiles to developed, and drops the middle quintile; Dev 3 divides the United Nations Human Development Index (HDI) into quartiles, assigns the first and second quartiles to developing and the third and fourth quartiles to developed³⁵; and Dev 4 uses the UN FAO’s Low Income Food Deficit Country (LIFDC) list to assign developing, and countries not listed are considered developed³⁴; Dev 5 assigns a country to developing if the World Bank GNI indicator is in the bottom two groups (low or lower-middle income) and assigns all others to developed; Dev 6 assigns a country to developing if the World Bank GNI indicator is in the bottom group (low income), assigns the country to developed if it is in the top group (high income), and drops the other countries from the sample³³.

We create categorical variables based on the detailed product descriptions to describe preservation form, including fresh, frozen, live, and “other,” which includes dried, salted, packed in oil, or smoked. We also create categorical variables to describe portion, which includes whole, fillet, meat, and “other portion.” The latter includes

livers, roe, and fins. We also create categorical variables to describe fish, crustaceans, or mollusks. For the regression analysis, we compute price per kg at the transaction level (year, commodity code, and exporter/importer combination) by dividing total value by total quantity.

Analysis

To compare nutrient per dollar for developing and developed countries, we test for differences between developed and developing nutritional content using all six ways of categorizing countries as developed or developing. Specifically, we compute one-sided Mann–Whitney non-parametric tests for percent difference in nutrients per dollar. We summarize mean percentage differences in nutrients per dollar in figures and compute analytical confidence intervals⁵⁷. We also conduct parametric *t* tests for differences in two ways: 1) treating each transaction equally and 2) weighting nutrients per dollar by the volume of the transaction.

All statistical tests (Mann–Whitney, *t* test, and weighted *t* test) are done on each nutrient using the full sample and a trimmed sample that drops the top 1% to eliminate potential outliers. To trim the sample, we iteratively sorted each nutrient per dollar in descending order and flagged observations that fall in the top 1%. We then trimmed the observations that are flagged at least once in the above iterative process, which leads to trimming about 3% of the total observations. The purpose of trimming the sample is to evaluate robustness of the main findings to dropping extreme observations. We also report all tests for the pooled sample (all years) and for each nutrient separated out by year (2015 through 2021). We furthermore conduct the tests while dropping China from the analysis, since China is the largest producer, consumer, exporter, and importer of seafood and is heavily engaged in re-exporting^{36,37}. We also create an indicator for re-exporter that includes a broader set of important seafood re-exporting countries—China, Netherlands, Poland, Thailand, and Vietnam—and report the tests when these countries are dropped from the sample. Moreover, all tests are conducted for each of our six development status classifications. This leaves us with 2592 sets of statistical tests: 2 (trimmed and untrimmed) × 9 (nutrients) × 8 (years, including 7 individual years and all years combined) × 3 re-export samples (drop none, drop China, drop broader set of re-exporters) × 6 (Dev 1 through Dev 6 development indicator).

To evaluate match quality (matching Comtrade to the FAO nutrition data), we conduct the 2592 different tests on three different subsamples: the full sample, exact one-to-one matches only, and a combination of one-to-one matches and multiple-to-one matches.

We run Seemingly Unrelated Regression (SUR) models to allow for correlation across nutrients in the nutrient per dollar outcome variables⁵⁸. We use natural log of nutrition per dollar and test for cross-equation restrictions that force all nutrient differences to be the same. To compare to other results, we convert the regression coefficients to percent differences: % change = $(e^{\beta} - 1) \times 100$.

To explain our main findings, we compute Oaxaca-Blinder decompositions. Specifically, we compute two-part Oaxaca-Blinder decompositions for each of nine nutrient per dollar measures using the omega option in the oaxaca command in Stata^{59–61}. Oaxaca-Blinder decompositions, which were developed originally to analyze wage differences in labor markets and diagnose wage discrimination, decompose differences in a dependent variable between two groups into differences that can be explained by differences in the covariates and a residual amount that cannot be explained by these differences. In our application, for example, the higher protein per dollar for developing country importers compared to developed country importers could be explained in part by developing countries having a larger share of frozen seafood in imports, and frozen product is less valued in the market than fresh, live, or other preservation.

We analyze covariate differences to assess supporting evidence for the Oaxaca-Blinder decompositions. Specifically, we compare differences between mean non-nutritional covariate levels for developed and developing countries. By comparing developed and developing country importer values for these characteristics, we can begin to understand differences in prices paid for seafood and associated nutritional content. We compare both unweighted and volume-weighted means of these characteristics.

To assess findings from the Oaxaca-Blinder decompositions further, we analyze the determinants of seafood prices using hedonic regressions. Specifically, we estimate multivariate hedonic regressions to decompose price per kg into the effects of individual attributes, including type of seafood (e.g., fish, crustacean, or mollusk), preservation form (e.g., frozen), portion (e.g., fillet), and year (to allow for inflation and changes in demand and supply conditions). The base category is frozen whole fish. We run a baseline model with no interactions and six other models that interact each of our six development indicators with the covariates in order to examine whether developed countries pay a premium or discount for a given product characteristic. Standard errors are clustered at the year level.

Data availability

Original source data are publicly available^{33–35,38,51–53,55,56}. Our complete merged dataset and code used in the analysis are available on Zenodo⁶².

References

1. Béné, C. et al. Contribution of fisheries and aquaculture to food security and poverty reduction: assessing the current evidence. *World Dev.* **79**, 177–196 (2016).
2. Bennett, A. et al. Recognize fish as food in policy discourse and development funding. *Ambio* **50**, 981–9 (2021).
3. Gephart, J. A. et al. Scenarios for global aquaculture and its role in human nutrition. *Rev. Fish. Sci. Aquac.* **29**, 122 (2020).
4. Golden, C. D. et al. Nutrition: Fall in fish catch threatens human health. *Nature* **534**, 317 (2016).
5. Hicks, C. C. et al. Harnessing global fisheries to tackle micronutrient deficiencies. *Nature* **574**, 95–98 (2019).
6. Thilsted, S. H. et al. Sustaining healthy diets: the role of capture fisheries and aquaculture for improving nutrition in the post-2015 era. *Food Policy* **61**, 126–131 (2016).
7. Belton, B. & Thilsted, S. H. Fisheries in transition: food and nutrition security implications for the global south. *Glob. Food Security* **3**, 59–66 (2014).
8. Golden, C. D. et al. Aquatic foods to nourish nations. *Nature* **598**, 315–320 (2021).
9. Nash, K. L. et al. Trade and foreign fishing mediate global marine nutrient supply. *Proc. Natl Acad. Sci.* **119**, e2120817119 (2022).
10. FAO. *The state of world fisheries and aquaculture 2022: towards blue transformation* (FAO, 2022).
11. Smith, M. D. et al. Sustainability and global seafood. *Science* **327**, 784–786 (2010).
12. Asche, F., Bellemare, M. F., Roheim, C., Smith, M. D. & Tveteras, S. Fair enough? Food security and the international trade of seafood. *World Dev.* **67**, 151–160 (2015).
13. Béné, C., Lawton, R. & Allison, E. H. “Trade matters in the fight against poverty”: narratives, perceptions, and (lack of) evidence in the case of fish trade in Africa. *World Dev.* **38**, 933–954 (2010).
14. Traverso, S. & Schiavo, S. Fair trade or trade fair? International food trade and cross-border macronutrient flows. *World Dev.* **132**, 104976 (2020).
15. Brinkman, H. J., De Pee, S., Sanogo, I., Subran, L. & Bloem, M. W. High food prices and the global financial crisis have reduced access to nutritious food and worsened nutritional status and health. *J. Nutr.* **140**, 153S–161S (2010).

16. Pinstrup-Andersen, P. Food security: definition and measurement. *Food Security* **1**, 5–7 (2009).
17. Cojocar, A. L. et al. The “seafood” system: aquatic foods, food security, and the global south. *Rev. Environ. Econ. Policy* **16**, 306–326 (2022).
18. Beveridge, M. C. et al. Meeting the food and nutrition needs of the poor: the role of fish and the opportunities and challenges emerging from the rise of aquaculture. *J. Fish. Biol.* **83**, 1067–1084 (2013).
19. Bronnmann, J., Smith, M. D., Abbott, J., Hay, C. J. & Næsje, T. F. Integration of a local fish market in Namibia with the global seafood trade: Implications for fish traders and sustainability. *World Dev.* **135**, 105048 (2020).
20. Rice, E.D. et al. Price volatility in fish food systems: spatial arbitrage as an adaptive strategy for small-scale fish traders. *Ecol. Soc.* **29**, 13 (2024).
21. Tveterås, S. et al. Fish is food—the FAO’s fish price index. *PLoS One* **7**, e36731 (2012).
22. Asche, F., Eggert, H., Oglend, A., Roheim, C. A. & Smith, M. D. Aquaculture: Externalities and policy options. *Rev. Environ. Econ. Policy* **16**, 282–305 (2022).
23. Asche, F., Bronnmann, J. & Cojocar, A. L. The value of responsibly farmed fish: a hedonic price study of ASC-certified whitefish. *Ecol. Econ.* **188**, 107135 (2021).
24. Roheim, C. A., Gardiner, L. & Asche, F. Value of brands and other attributes: Hedonic analysis of retail frozen fish in the UK. *Mar. Resour. Econ.* **22**, 239–253 (2007).
25. Hukom, V., Nielsen, M., Ankamah-Yeboah, I. & Nielsen, R. A hedonic price study on warm-and cold-water shrimp in Danish retail sale. *Aquac. Econ. Manag.* **24**, 1–19 (2020).
26. Ray, K. D., Lew, D. K. & Kosaka, R. Hedonic price functions and market structure: an analysis of supply-motivated submarkets for salmon in California. *Mar. Resour. Econ.* **37**, 135–154 (2022).
27. Garlock, T. et al. Aquaculture: The missing contributor in the food security agenda. *Glob. Food Security* **32**, 100620 (2022).
28. Garlock, T. M. et al. Environmental, economic, and social sustainability in aquaculture: the aquaculture performance indicators. *Nat. Commun.* **15**, 5274 (2024).
29. Gephart, J. A. et al. Globalization of wild capture and farmed aquatic foods. *Nat. Commun.* **15**, 8026 (2024).
30. Belton, B., Bush, S. R. & Little, D. C. Not just for the wealthy: Rethinking farmed fish consumption in the Global South. *Glob. Food Security* **16**, 85–92 (2018).
31. Asche, F., Bremnes, H. & Wessells, C. R. Product aggregation, market integration, and relationships between prices: an application to world salmon markets. *Am. J. Agric. Econ.* **81**, 568–581 (1999).
32. Asche, F., Oglend, A. & Smith, M. D. Global markets and the commons: the role of imports in the US wild-caught shrimp market. *Environ. Res. Lett.* **17**, 045023 (2022).
33. The World Bank. How does the World Bank classify countries? <https://datahelpdesk.worldbank.org/knowledgebase/articles/378834-how-does-the-world-bank-classify-countries> (2024).
34. Food and Agriculture Organization of the United States (FAO). Low Income Food Deficit Countries (LIFDC). <https://data.apps.fao.org/catalog/dataset/special-country-groups/resource/2967dcfe-aa26-44af-afde-e97ca5e30450> (2022).
35. United Nations Development Programme (UNDP). Human Development Index (HDI). <https://hdr.undp.org/data-center/documentation-and-downloads> (2022).
36. Asche, F. et al. China’s seafood imports—not for domestic consumption?. *Science* **375**, 386–388 (2022).
37. Abott, J. K., Willard, D. & Xu, J. Feeding the dragon: the evolution of China’s fishery imports. *Mar. Policy* **133**, 104733 (2021).
38. Food and Drug Administration. Daily Value and Percent Daily Value on the Nutrition and Supplement Facts Labels. <https://www.fda.gov/food/nutrition-facts-label/daily-value-nutrition-and-supplement-facts-labels> (2023). Accessed January 8, 2025.
39. Zhao, K., Gaines, S. D., Garcia Molinos, J., Zhang, M. & Xu, J. Effect of trade on global aquatic food consumption patterns. *Nat. Commun.* **15**, 1412 (2024).
40. Ferraro, P. J., Sanchirico, J. N. & Smith, M. D. Causal inference in coupled human and natural systems. *Proc. Natl Acad. Sci.* **116**, 5311–5318 (2019).
41. Chen, R., Hartarska, V. & Wilson, N. L. The causal impact of HACCP on seafood imports in the US: an application of difference-in-differences within the gravity model. *Food Policy* **79**, 166–178 (2018).
42. Asche, F., Roheim, C. A. & Smith, M. D. Trade intervention: Not a silver bullet to address environmental externalities in global aquaculture. *Mar. Policy* **69**, 194–201 (2016).
43. Liverpool-Tasie, L. S. O., Sanou, A., Reardon, T. & Belton, B. Demand for imported versus domestic fish in Nigeria. *J. Agric. Econ.* **72**, 782–804 (2021).
44. Tezzo, X., Aung, H. M., Belton, B., Oosterveer, P. & Bush, S. R. Consumption practices in transition: rural-urban migration and the food fish system in Myanmar. *Geoforum* **127**, 33–45 (2021).
45. Reardon, T., Timmer, C. P., Barrett, C. B. & Berdegue, J. The rise of supermarkets in Africa, Asia, and Latin America. *Am. J. Agric. Econ.* **85**, 1140–1146 (2003).
46. Belton, B., Reardon, T. & Zilberman, D. Sustainable commoditization of seafood. *Nat. Sustain.* **3**, 677–684 (2020).
47. Koehn, J. Z., Allison, E. H., Golden, C. D. & Hilborn, R. The role of seafood in sustainable diets. *Environ. Res. Lett.* **17**, 035003 (2022).
48. Robinson, J. P. et al. Managing fisheries for maximum nutrient yield. *Fish. Fish.* **23**, 800–811 (2022).
49. Abbott, J. K., Lew, D. K., Whitehead, J. C. & Woodward, R. T. The future of fishing for fun: the economics and sustainable management of recreational fisheries. *Rev. Environ. Econ. Policy* **16**, 262–281 (2022).
50. Kroetz, K., Nøstbakken, L. & Quaas, M. The future of wild-caught fisheries: Expanding the scope of management. *Rev. Environ. Econ. Policy* **16**, 241–261 (2022).
51. United Nations. UN Comtrade Database, <https://comtrade.un.org/> (2023).
52. Food and Agriculture Organization of the United Nations (FAO). *FAO/INFOODS Global Food Composition Database for Fish and Shellfish Version 1.0 - uFish1.0* (FAO, 2016).
53. Food and Agriculture Organization of the United Nations (FAO). Fisheries and Aquaculture FishStatJ, <https://www.fao.org/fishery/en/global-search?q=statistics%20software%20fishstatj%20en&lang=en> (2023).
54. Dietz, D. & Colson Leaning, D. *Effects of the global seafood trade on health and nutritional security*, Master’s Project (Nicholas School of the Environment, Duke University, 2019).
55. MEXT. *Standards tables of food composition in Japan*, 7th ed. Ministry of Education, Culture, Sports, Science, and Technology - Japan, https://www.mext.go.jp/en/policy/science_technology/policy/title01/detail01/sdetail01/sdetail01/1385122.htm (2015).
56. The World Bank. GDP per capita, PPP (constant 2017 international dollars). <https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.KD> (2022).
57. Miller Jr, R.G. *Beyond ANOVA: basics of applied statistics* (CRC press, 1997).
58. Zellner, A. An efficient method of estimating seemingly unrelated regressions and tests for aggregation bias. *J. Am. Stat. Assoc.* **57**, 348–368 (1962).

59. Blinder, A. S. Wage discrimination: reduced form and structural estimates. *J. Hum. Resour.* **8**, 436–455 (1973).
60. Oaxaca, R. Male–female wage differentials in urban labor markets. *Int. Econ. Rev.* **14**, 693–709 (1973).
61. Jann, B. The Blinder–Oaxaca decomposition for linear regression models. *Stata J.* **8**, 453–479 (2008).
62. Data and code for “The Global Seafood Trade. Embodied Nutrients, and Nutritional Affordability. Zenodo <https://doi.org/10.5281/zenodo.15346063> (2025).

Acknowledgements

For helpful comments and suggestions, the authors thank Betsy Albright, Frank Asche, Rachel Karasik, and Jeff Vincent; participants in Duke’s Nicholas School of the Environment Master’s Project Symposium; seminar participants at the Duke University Marine Lab and Mississippi State University; and conference participants at the International Institute of Fisheries Economics and Trade and the North American Association of Fisheries Economists. For financial support, Y.L. and M.D.S. thank the Knobloch Family Foundation, Y.L. thanks the Andrew W. Mellon Foundation Endowed Fund for Innovative Research and the Grayce B. Kerr Fund in Support of Assistant Scientists at Woods Hole Oceanographic Institution, A.S. thanks Oceanskind, and T.Y. thanks the WHOI Summer Student Fellowship and WHOI Academic Programs Office Funds.

Author contributions

M.D.S. conceived of the study and wrote the paper. Y.L. and M.D.S. supervised the research. Y.L., M.D.S., and J.K.A. designed the study. Y.L., M.D.S., D.D., D.C.L., A.S., and T.Y. built the database, analyzed the data, and prepared tables and figures. Y.L., M.D.S., and J.K.A. interpreted the results. Y.L., M.D.S., J.K.A., D.D., D.C.L., A.S., and T.Y. revised and edited the paper.

Competing interests

The authors declare no competing interests.

Additional information

Supplementary information The online version contains supplementary material available at <https://doi.org/10.1038/s41467-025-61012-9>.

Correspondence and requests for materials should be addressed to Martin D. Smith.

Peer review information *Nature Communications* thanks the anonymous reviewers for their contribution to the peer review of this work. A peer review file is available.

Reprints and permissions information is available at <http://www.nature.com/reprints>

Publisher’s note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Open Access This article is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License, which permits any non-commercial use, sharing, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if you modified the licensed material. You do not have permission under this licence to share adapted material derived from this article or parts of it. The images or other third party material in this article are included in the article’s Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article’s Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by-nc-nd/4.0/>.

© The Author(s) 2025