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Incorporating Nutritional Accounts to the GTAP Data Base

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With a wide range of implications for welfare, food security, land use, trade and the environment, nutrition-related policies pose complex questions that should be assessed using an approach that properly accounts for all the involved interactions. Widely used partial equilibrium models fail to properly account for the post-farmgate food value chains. At the same time, most of the available integrated assessment and computable general equilibrium models have some major limitations in terms of the consistent representation of nutritional data flows. In this paper, we address some of the limitations identified in the literature and develop an approach for incorporating nutritional accounts into the Global Trade Analysis Project (GTAP) Data Base, tracing quantities of food, calories, fats, proteins and carbohydrates along the value chains. We further showcase how the developed nutritional database can be linked to the standard GTAP model. A sample application is developed in the paper to provide an assessment of the impact of import tariff elimination on nutritional flows.

JEL codes: D57, D58, L66, Q11, Q18.

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1. Introduction

Elimination of global hunger is identified as one of the key goals in the sustainable development agenda, as over 800 million people worldwide (approximately 1 in 9) are undernourished (UN, 2015; FAO, et al., 2019). At the same time, more than 1.9 billion adults worldwide are estimated to be overweight and of these, over 650 million are obese (WHO, 2020). The dual burden of under- and over-nourishment poses significant challenges for the future of food systems.

Major transformations in food systems are also required to reduce the agricultural and food impact on the environment. According to the

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Intergovernmental Panel on Climate Change (IPCC), agriculture, forestry and other land use activities contribute approximately a quarter of the global greenhouse gas (GHG) emissions. Demographic changes and increasing incomes are expected to further push the global diet towards more emission-intensive meat consumption, as a result, agricultural GHG emissions could significantly increase in the long-run. According to Hedenus et al. (2014), with no shifts in the global diet, food-related emissions could grow from 7.1 gigatonnes (Gt) CO_2-equivalent per year in 2000 to 13 Gt CO_2-eq. per year in 2070, which would make it almost impossible to keep the global temperature increase well below 2°C, a stated objective of the Paris Climate Agreement (UNFCCC, 2020). In order to target environmental-friendly changes in food consumption patterns, an explicit representation of nutritional flows is needed in the assessment framework. In addition, it is important to be able to trace volume flows of other supply-use categories within the assessment. For instance, earlier studies have shown that reducing food loss and waste is an important step to enhance food security and environmental sustainability (Shafiee-Jood and Cai, 2016; Vilariño et al., 2017). In this context, an explicit tracing of food loss and waste flows is needed to properly address the corresponding issue.

With a wide range of implications for welfare, food security, land use, trade and the environment, food-related policies represent a complex question that should be assessed with a set of modelling tools that account for such interactions. Integrated assessment models (IAMs) and computable general equilibrium (CGE) models represent modelling approaches that fulfill such requirements. At the same time, as of today, there have not been many applications of IAMs and CGE models, with an explicit representation of nutritional information. Several exceptions include Sands et al. (2014), Hasegawa et al. (2015), Bouët et al. (2014) and van Meijl et al. (2020).

As Yi et al. (2021) show, post-farmgate food value chains make up most of food expenditures globally, with a corresponding share exceeding 80% in some countries and projected to grow further, especially in developing economies. In this regard, it is very important to be able to track the nutritional content beyond the farm gate in order to properly account for the environmental, social and economic dimensions of the post-farm supply chains. Due to the complete coverage of an economy and an explicit representation of inter-sectoral linkages, CGE models, as opposed to partial equilibrium modelling tools, provide much better opportunities to address this issue. Nevertheless, in the available literature, most studies focus on changes in agricultural and food production and consumption patterns, without explicitly tracing nutritional content embodied in final consumption. Some selected studies that deal with the latter question are discussed below.

At the country level, Minot (1998) examines distributional and nutritional impacts of devaluation in Rwanda by linking a CGE model with a microsimulation framework. A similar approach is applied by Pauw and Thurlow (2011) to link growth, poverty and nutrition in Tanzania using a CGE-microsimulation framework. At the multi-country level, several studies rely on the Global Trade Analysis Project (GTAP) Data Base and global CGE models to undertake an assessment of different policies for nutritional outcomes. Hertel et al. (2007) provide an assessment of nutritional impacts from rapid economic growth in China and India. Verma and Hertel (2009) examine the impact of commodity price volatility on nutritional attainment of households at the nutritional poverty line in Bangladesh. Chepeliev and Aguiar (2019) explore the economy-wide environmental and dietary impacts of the global greenhouse gas taxes on food products.

All these studies directly map nutritional content by commodities to the GTAP agricultural and food sectors, without accounting for out-of-home food consumption or explicitly tracking the transformation from primary to processed commodities.

This limitation is partly addressed in Rutten et al. (2013), who develop an approach for calculating nutritional indicators in a CGE framework, with particular application for the MAGNET model. The authors combine the Food and Agricultural Organization (FAO) nutritive indicators with the FAO primary production data, map these estimates to the GTAP primary sectors, and calculate the nutrient content of processed food and food related services. The latter step is performed via an iterative procedure. The first approximation is used to allocate primary commodities to processed food sectors, a second round considers input of processed food (outcome of the first approximation) used to produce processed food and so on. After performing these operations, Rutten et al. (2013) estimate per capita nutrition outcomes, which are on average 10% to 45% higher (at the global level) than those reported by FAO. The authors implement scaling factors to match the FAO data.

The latter adjustment implies that some loss of nutritional content that happens during the transformation process is not accounted for in their framework. In particular, when primary commodities are combined to produce processed commodities, the caloric content of the processed commodity (in primary commodity equivalent), in general, is lower than the caloric content of the corresponding primary commodity (per unit of weight).

Another limitation presented in Rutten et al. (2013) and several other available studies includes the fact that the developed methodology does not explicitly account for (or track) non-food use categories, such as feed, seed, losses and other non-food uses. While this might not be critical for the nutritional data representation in the base year, in a dynamic simulation framework, it would be important to track the primary food supply and its allocation through the whole supply-use chain for each simulated year.

One other point not being properly addressed in the existing literature includes consistent representation of out-of-home food consumption. For instance, Britz (2020) designs a method where nutritional information is traced through the input-output table using a Leontief inverse, though the out-of-home food consumption is not captured within this framework.

At the same time, in many countries, the share of food consumed out of home represents a significant part of the nutritional intake. For instance, according to Saksena et al. (2018), out-of-home food consumption in the U.S. is around 34%. In some other developed countries, this share is somewhat lower, but still substantial—27.8% in Denmark, 25.8% in Sweden, 23.5% in the United Kingdom, 21.4% in Germany and 15.4% in Greece (Orfanos et al., 2009). Furthermore, this food consumption is allocated among different service activities, such as hotels, restaurants, hospitals, schools, government sector, etc. Proper representation of this nutritional intake channel is an important part of the food balance sheet's (FBS) incorporation into CGE models and IAMs.

In this paper, we address some of the limitations discussed above and develop an approach toward incorporation of nutritional information to the GTAP Data Base with FAO-based agricultural production targeting (Aguiar et al., 2019; Chepeliev, 2020),[2] tracing quantities of food, calories, fats, proteins and carbohydrates along the value chains. We rely on the FAO FBS data and nutritive factors to estimate nutritional content of primary commodities and derived commodities represented in primary commodity equivalent within FBS. Calories, fats, proteins and carbohydrates are estimated and reported. We further identify use categories that account for food, feed, seed, losses and other uses. In terms of the food supply, we identify GTAP primary commodity sectors, food processing sectors and service sectors that supply food. To trace nutritional data by GTAP sectors, we construct Leontief inverses, operating only over those sectors (and uses) that supply food. Such inverses are constructed separately for the tracing of domestic, exported and imported commodities. Estimates of food supplied by service sectors are compared with available country-specific data. The approach is applied to all four GTAP 10 reference years and nutritional data are mapped to the domestic and imported use flows in the final database. The approach can be replicated for each simulated year in the context of dynamic policy runs.

The rest of the paper is organized as follows. Section 2 provides an overview of the methodology for incorporating the nutritional accounts into the GTAP Data Base. Section 3 provides an overview of the constructed nutritional database. Section 4 discusses an illustrative application of the constructed database in which a static GTAP model is used to assess the impacts of the import tariffs elimination

[2] This paper is based on Version 10 of the GTAP Data Base with 4 reference years: 2004, 2007, 2011 and 2014.

on nutritional outcomes. Finally, Section 5 discusses directions toward further enrichment of the GTAP nutritional data framework and concludes.

2. Methodological approach

In this section, we discuss a general approach for the incorporation of nutritional accounts into an input-output modelling framework. We first showcase this using a simplified example of a single-country economy with four commodities and activities, export and import flows, and one final consumer. We then discuss in more detail the specific data processing steps for the incorporation of nutritional accounts into the GTAP Data Base.

2.1. Single country example

To illustrate the general concept of the incorporation of nutritional accounts into an input-output (IO) framework, we first focus on a single-country example. Assume that we have an IO table with four sectors—agriculture, processed food, industry and services. Each of these sectors supplies goods and services for final consumption, intermediate use and exports. Domestic and imported commodities are used as intermediate inputs and for final consumption. All data inputs and replication steps discussed in this section are included in the Excel file that accompanies the paper.

Though this is a stylized example, the cost shares of the input-output table (Table 1) largely follow the structure of the U.S. IO table from the GTAP 10 Data Base for the 2014 reference year (Aguiar et al., 2019). With a total final consumption of 165.4 USD, one might interpret this IO table as a representation of the economy per household per day (in such case, annual final consumption would be 165.4 (USD) x 365 (days) = 60371 USD).

Table 1. Input-output table for stylized example, USD

	Agriculture	Food	Industry	Services	Final cons.	Exports	Imports	**Total**	Food-related output
Agriculture	0.6	3.0	0.4	0.4	1.7	1.4	-1.8	**5.7**	NA
Food	0.6	3.3	0.4	2.8	11.0	4.2	-7.2	**15.1**	14.4
Industry	0.8	1.6	49.3	25.8	22.7	46.9	-49.7	**97.4**	NA
Services	0.8	3.5	19.4	82.0	130.0	16.1	-14.7	**237.1**	127.6
Value added	2.9	3.7	27.9	126.1					
Total	**5.7**	**15.1**	**97.4**	**237.1**	**165.4**	**68.6**	**-73.4**		

We further assume that the following information is available— domestic production (4100 grams), trade in primary agricultural commodities (exports—600 grams and imports—600 grams) and imports of the processed food (600 grams).

We assume that all primary agricultural commodities correspond to a single sector in the IO table—agriculture, while all imported processed food commodities are associated with the processed food sector.

Different treatments are applied to the tracing of the primary and imported processed commodities. As discussed in Section 2.1, we first trace primary domestic and imported commodities in each country and region of the GTAP Data Base. This allows us to estimate the primary-equivalent content of the processed food – supplied domestically and exported. In the next step, we trace imported processed commodities within the developed framework. In the single country example below, we assume that the tracing of primary commodities and their transformation to processed commodities has already been implemented in the rest of the world and corresponding flows are given (600 grams – imports of processed food).

We start with the allocation of primary commodities. From the domestic production (4100 grams) we subtract exports (600 grams), add imports (600 grams) and deduct losses (in our case we assume that these are 100 grams), allocating the rest (4000 grams) between direct food consumption of primary commodities and other uses. In order to do this, we estimate the value shares of agriculture commodities (domestic + imported) used by agriculture, processed food, industry, services and final consumers. We assume that although Industry uses some primary agricultural commodities, these correspond to non-food uses and thus do not supply any food to final consumers. We also assume that the self-consumption by agriculture corresponds to seed. In the case of the GTAP nutritional database construction process, both non-food use and seed flows are implied directly from the FAO database, as discussed in the next section.

This approach suggests that out of 4000 grams of primary commodities, 1114.8 grams are consumed directly (final consumption of agriculture) and the rest (2885.2 grams) corresponds to the intermediate use. Out of these 2885.2 grams, 393.4 grams is self-consumption by agriculture (i.e. seed), 262.3 grams are consumed by industry (other uses), 1967.2 grams are consumed by the processed food sector and 262.3 grams by services. In our example, the two latter sectors further transform primary commodities to supply food to final consumers and for exports (a total of 2229.5 grams), while the remaining 655.7 grams (agriculture and industry) correspond to the non-food uses and are not further allocated. It should be noted that while in this illustrative single country example, all uses are derived based on value shares and thus assuming a law of one price, this is not the case for the full-scale implementation. In the case of the GTAP nutritional database consumption process, both non-food use and seed flows are implied directly from the FAO database, as discussed in the next section.

In the next step, we estimate volume supplied per food-related output (grams per 1 USD – grams/USD) for processed food and services. We take into account only output associated with the supply of food (Table 1). In particular, in the case of the processed food industry, this excludes intermediate use of processed food by agriculture and industry (processed food use by services is included). In the case of services, all categories except final consumption are excluded, as we assume services neither provide any food to other sectors of the economy nor export any food. The latter assumption is also applied in the GTAP nutritional database construction process.[3] As a result, the processed food sector supplies 136.6 grams/USD for food-related output, while services supply 2.1 grams/USD for food-related output (Table 2).

Table 2. Indicators for primary agriculture commodities tracing

	Supply of primary commodities, grams	Food-related intermediate use, grams	Supplied volume per output, grams/USD
Agriculture	393.4	-	-
Processed food	1967.2	1967.2	136.6
Industry	262.3	-	-
Services	262.3	262.3	2.1
Final consumption (direct)	1114.8	-	-
Losses	100.0	-	-
Exports	600.0	-	-
Total	**4700.0**	**2229.5**	**-**

Notes: numbers highlighted in red indicate non-food use categories within the domestic supply accounting. Numbers reported in the table are rounded to the first decimal point.

Next, we estimate intermediate use shares for the domestic product use (Table 3), but only for the case of food-related uses. To estimate such shares, we use food-related output estimated in the previous step. Such instances include agriculture

[3] This is a simplifying assumption. In reality there could be some food-related flows embodied in the trade in services, but those are relatively minor in most cases. Looking at the global average shares for the case of accommodation and food services sector in GTAP ("afs"), around 3% of output of the sector is traded (Aguiar et al., 2019). While in some countries the traded share is substantially higher it is not clear to what extent this value flow corresponds to the embodied food flows (i.e. if one follows the uniform price assumption to allocated domestic and exported "afs" food supply). In particular, one might expect that the corresponding value flow primarily includes services, while a large share of food used in the hired foreign catering service would be purchased domestically or imported as food (and not service), e.g. truffles from France. In addition, current GTAP procedures to construct the bilateral trade in "afs" use strong assumptions to develop such flows, since services trade data used in GTAP is available at a much more aggregate sectoral level. In addition to the points discussed above, a possible tracing of food flows embodied into trade in services would further complicate the developed procedures. Therefore, we leave this potential improvement for future nutritional database releases, also considering the fact that the upcoming GTAP 11 release would use a more elaborate treatment of trade in services.

and processed food use by the processed food and services sectors (a total of four instances in our case).

Table 3. Matrix of domestic use, USD

	Agriculture	Food	Industry	Services	Final cons.	**Total**
Agriculture	0.5	2.2	0.3	0.3	1.0	**4.3**
Processed food	0.5	2.3	0.2	2.2	5.7	**10.9**
Industry	0.5	1.0	24.0	16.9	8.1	**50.5**
Services	0.7	3.1	16.6	73.0	127.6	**221.0**
Total	**2.2**	**8.6**	**41.1**	**92.4**	**142.4**	

Table 4 reports this matrix with intermediate consumption shares. This matrix is further inverted and multiplied by the vector of volume supplied per food-related output. As a result, we estimate that out of 2229.5 grams supplied by processed food and services, 620.0 grams are supplied to final consumers by services, 926.7 grams are supplied to final consumers by the processed food sector and 682.8 grams are exported by the processed food sector (Table 5). Adding 1114.8 grams (direct consumption of primary commodities) to the first two categories from the above will give us an estimate of direct and indirect consumption of primary commodities by final consumers (2661.4 grams).

To account for all sources of supply, imported processed commodities need to be introduced to the accounting framework (600 grams in our example). An approach to the tracing of these calories is similar to the tracing of primary agricultural commodities, though several modifications apply. First, to estimate the share of the final consumption of imported processed food, the matrix of imports is used (Table A.1, Appendix A), instead of the IO table shares (in the case of primary commodities supply). In our example, out of 600 grams of imported processed food, 460.9 grams are consumed by final consumers directly. The remaining 139.1 grams are further allocated between processed food and services.

Table 4. Intermediate consumption shares corresponding to the food-related output for primary commodities tracing

	Agriculture	Food	Industry	Services	Final cons.
Agriculture	0	0.153	0	0.002	0
Processed food	0	0.160	0	0.017	0
Industry	0	0	0	0	0
Services	0	0	0	0	0

Notes: numbers reported in the table are rounded to the third decimal point.

Table 5. Indicators for the tracing volumes from primary commodities supplied by processed food and services

	grams/USD of final consumption/exports	Total grams from final consumption	Total grams from exports
Agriculture	-	-	-
Processed food	162.6	926.7	682.8
Industry	-	-	-
Services	4.9	620.0	-
Total	**-**	**1546.7**	**682.8**

Notes: we assume that services do not export any food. Volumes that go directly to the final consumption, i.e. within agriculture, are not represented in the table. Numbers reported in the table are rounded to the first decimal point.

For simplicity, in this example, we assume that all imported processed food ends up in the final consumption, so it does not go for exports or other uses (e.g. feed, seed, etc.). Therefore, when supplied volume per food-related output (grams/USD) is estimated, exports of both processed food and services are excluded from the food-related output. When intermediate use shares are estimated (Table A.2, Appendix A), only instances of processed food use by processed food and services are considered. As in the case of primary agricultural commodities tracing, the inverted matrix of use shares is multiplied by the vector of supplied volumes per food-related output to get the estimate of grams supplied to final consumers. We estimate that 62.7 grams of imported processed food are supplied to final consumers by the processed food sector and 76.4 grams by services, in addition to the 460.9 grams directly supplied by the processed food sector (Table A.3, Appendix A).

In the example above, we assume that the quantity of exported processed commodities is not given and thus is estimated by the tracing process. In general, this is not the case. FBS reports quantities of exported primary and limited number of processed food commodities, as well as corresponding nutritional content. This situation complicates data processing steps in our example, as FAO-reported and our estimated volumes of export do not necessarily match. While not pursued in the example above, these accounts could be reconciled by adjusting the reallocation of domestically consumed and exported processed foods to match FAO data.

After the volume flows have been traced within the developed framework, nutrition factors could be applied to derive the nutritional content. The latter might not necessarily represent a point estimate, but could be estimated in terms of upper, lower and median values to reflect the uncertainty depending on the food composition tables (Smith et al., 2016).

2.2. Overview of the processing steps for the case of GTAP Data Base

The single country example discussed above provides an overview of the general approach to the incorporation of nutritional accounts into the IO framework. Transition to the multi-region framework with a higher number of primary agricultural, food processing and service sectors, introduces additional elements to the general approach. Figure 1 provides an overview of the overall approach toward incorporation of the nutritional accounts into the GTAP Data Base.

In the ***first step,*** we identify sectors of the GTAP 10 Data Base that supply food to final consumers, as well as intermediate uses associated with food supply. We split sectors into three categories – those that supply primary agricultural commodities for food, processed food sectors and service sectors that supply food. Appendix B provides the corresponding sectoral classification listing. As in the single country example above (Section 2.1), we estimate food-related output for the tracing of primary agricultural commodities and imported processed commodities. We then estimate intermediate use matrixes, considering only instances associated with food-related uses. This is done separately for the tracing of primary agricultural commodities and imported processed commodities. For each of the 141 GTAP 10 Data Base regions we find an inverse of the two matrixes (65 sectors x 65 sectors), following the single country example above. First, an inverse is constructed for intermediate consumption shares of primary commodities (similar to the matrix from Table 4 in a single country case). Second, an inverse is constructed for intermediate consumption shares of imported processed commodities (similar to the matrix A.2 (Appendix A) from the single country example). These matrices are used in the following data processing steps.

In the ***second step***, we process the bilateral trade data. We source the quantities of bilateral imports and exports from FAO (2020a). We rely on imports (rather than exports) to construct the bilateral trade flows, assuming that importers are more reliable trade data reporters, as it is in their interest for taxation purposes to provide more precise trade flows accounting. However, in some instances, only exports are reported in the FAO database. In such cases we gap fill bilateral imports using exports. Bilateral trade data are collected for 424 commodities and 255 countries for the 2003-2015 timeframe.

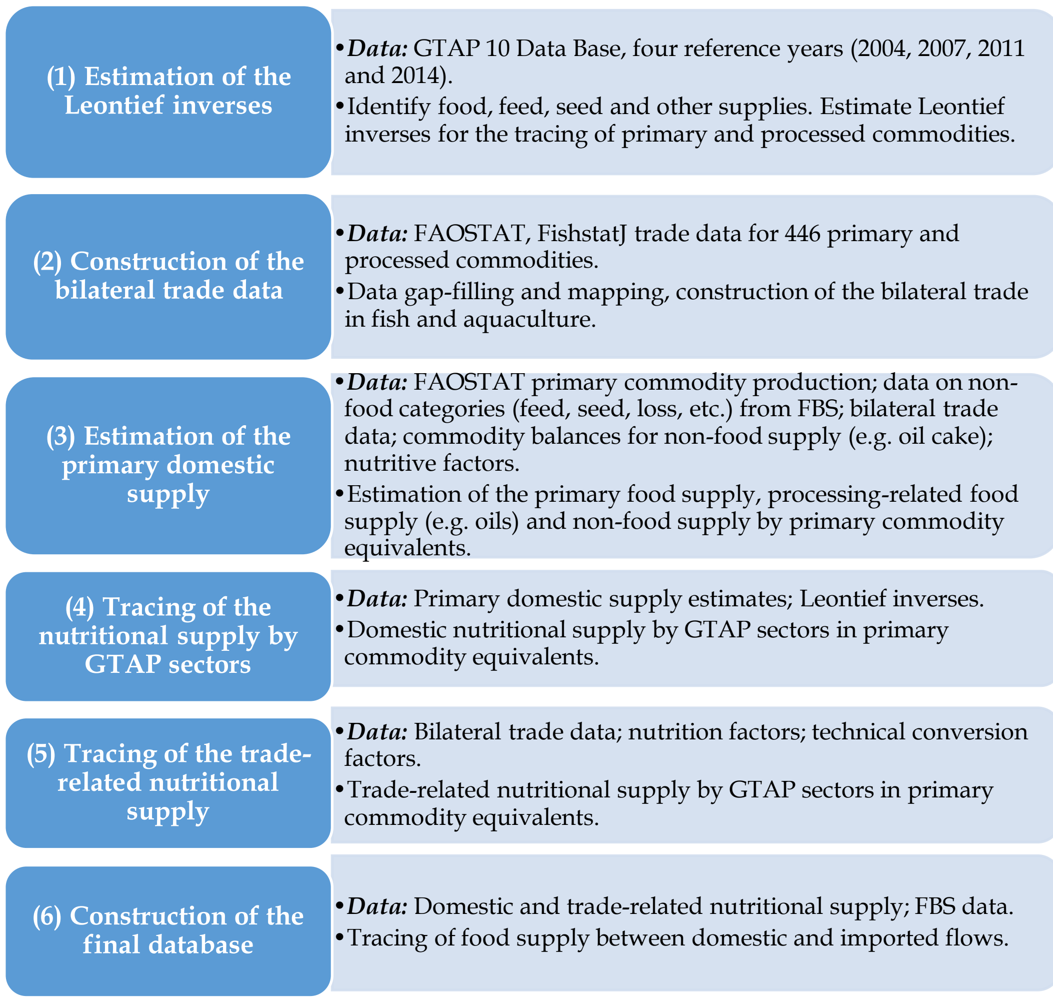

Figure 1. Overview of the data processing steps toward incorporation of nutrition accounts to the GTAP Data Base
Source: Author.

For the case of aquaculture and fish commodities, FAO (2020a) does not report quantities of bilateral trade. We source data on quantities of fish and aquaculture exports and imports by country from FishStatJ (FAO, 2020b). Aquaculture and fish trade data are sourced for 64 commodities, 220 countries and 2003-2015 reported years. These data are first adjusted to exclude re-exports (explicitly reported in the FishStatJ database) and then scaled at the commodity level, so that global exports match global imports. The 64 commodities reported in the FishStatJ database are further aggregated to match the commodity classification used in the construction of the nutritional accounts for the GTAP Data Base. Appendix S.1 (supplementary information) reports the mapping between 64 FishStatJ commodities and 22 aggregate commodity categories, consistent with the FBS classification. We split 10 (out of 12) fish and aquaculture FBS categories into primary and processed products (this results in 22 categories in total), which can then be mapped using correspondence to the FBS categories.

To construct the bilateral trade flows in fish and aquaculture, we use the unilateral data on quantities of exports and imports from FishStatJ and GTAP 10 Data Base bilateral trade data (value flows) in fish ('fsh' sector). We first bilateralize the FishStatJ trade flows using GTAP bilateral trade in fish as weights.[4] We then use the RAS[5] technique to balance the bilateral trade data (in tonnes), matching the FishStatJ-reported totals by exporting and importing countries. This is done for 22 commodity categories and 220 countries.

In the ***third step***, we collect data on quantities of crops and primary livestock production (FAO, 2020a). Nutritive factors that report calories, proteins, fats and carbohydrates per 100 grams of primary and processed commodities are collected from several data sources (FAO, 2020c; FAO, 2013; Gebhardt and Thomas, 2002). These nutritive factors are derived for 402 products and are used to estimate the nutritional content of traded commodities at a later data processing step (Appendix S.2). Some of the agricultural commodities with reported trade and production data are not used for food, feed or seed, but utilized in other non-food related processes (e.g. textiles industry, chemical products, etc.). For such commodity cases, we do not collect nutritive factors and thus they are not reported in Appendix S.2.

Nutritional information from the FBS is also collected at this stage. FAO provides this FBS in two different formats – using a new and an old methodology. The FBS that uses the new methodology covers the 2014-2017 timeframe, while the FBS based on the old methodology provides estimates prior to 2014. As in the data construction approach we are covering the 2004-2014 timeframe, using a three-year average to represent each GTAP reference year, we need to use both forms of the FBS and thus some harmonization steps are required. In particular, this includes remapping of the residuals and tourist use categories from the new FBS format to stock changes and non-food use in the old FBS format.

In terms of the data inputs, as of mid-2021 FAO has provided two releases of the FBS using the new methodology – 2020 and 2021 revisions (both covering data

[4] Using Comtrade data (instead of GTAP) to bilateralize the FishStatJ trade flows is one possible improvement. The latter though would require reconciliation of commodity classifications between FishStatJ and Comtrade. Also, considering that within the GTAP nutritional database construction process fish-related flows are further aggregated and represented with a single GTAP sector ('fsh'), a potential improvement from the corresponding more detailed treatment is somewhat limited.

[5] For the discussion of RAS balancing method see e.g. Trinh and Phong (2013).

for 2014 and onwards). A comparison of the 2021 revision and the 2020 revision using nutritional accounts for the historical data years (2013 and earlier) revealed some inconsistent reporting patterns for the selected food categories in the more recent revision. In particular, in 16 FBS categories,[6] the share of food that goes for processing has increased significantly (compared to the 2020 release) – in some cases over 100 times. To keep the methodological consistency across years, we have used the 2020 FBS release to represent nutritional accounts for these 16 food categories, while the remaining 80 food categories are approximated using the 2021 FBS release.

While FAO provides FBS accounts for over 178 countries worldwide, these do not cover all countries reported by FAO agricultural production accounts and considered in the GTAP Data Base. To estimate the FBS nutritional accounts for non-reported countries, we assign each missing country a 'like' country from the same region and with the closest per capita GDP level. Appendix S.3 reports mapping between countries without available FBS, but with reported FAO production and trade data, and 'like' countries. In all these cases, we assume that the per capita nutritional profile of countries without reported FBS is the same as in the 'like' countries.[7] To estimate per capita nutritional indicators we rely on the GTAP population data, rather than FAO population accounts, to be consistent with the GTAP 10 Data Base. The only exception is the South Sudan population data, which we source from the World Bank (WB, 2020). While most of the missing countries are small economies with populations below 0.5 million people (38 out of 56 gap-filled countries), there are some cases of larger countries (with populations above 10 million people) that need to be gap-filled. These include Democratic Republic of the Congo (74.9 million people as of 2014), Syrian Arab Republic (18.8 million), Burundi (10.8 million), South Sudan (10.6 million) and Somalia (10.5 million) (Appendix S.3). But even with several larger countries without reported FBS, such gap-filling covers a relatively small portion of the global nutritional supply, as the share of population of the gap-filled countries in the world totals is around 2.3%.

In a number of cases, there are inconsistencies within FBS accounts. For instance, reported production does not match supply and use accounts or reported food supply is negative. By construction of the FBS, production equals domestic use (food + feed + seed + processing + other uses), plus exports, minus supply from imports and stock variation. However, this identity does not hold for all

[6] The corresponding 16 categories include the following: Sweet potatoes, Palm kernels, Soyabean Oil, Sunflowerseed Oil, Rape and Mustard Oil, Cottonseed Oil, Palmkernel Oil, Palm oil, Coconut Oil, Ricebran Oil, Maize Germ Oil, Oranges, Mandarines, Lemons, Limes and products, Citrus, Other, Cocoa Beans and products, Milk - Excluding Butter.

[7] This treatment can be improved by additionally relying on available trade and production accounts for gap-filled countries.

countries and commodities. To overcome this issue, we adjust production using the identity listed above.[8] We re-estimate domestic supply after adjusting the production volumes. If cases of negative domestic supply are still present after these adjustments, we set the domestic supply to "0" and adjust stock variation to be consistent with the reported production volumes. The latter adjustment is needed mostly for small economies. For instance, for 2014 the number of country-commodity pairs with negative food supply is 47, which is around 0.2% of all reported cases.

We next estimate primary domestic supply for crops, livestock and fish commodities. To accomplish this task, we combine several data sources – production data from FAO,[9] trade in primary and processed commodities and FBS accounts. Several steps are implemented to align and harmonize these data inputs. We distinguish five supply categories for which we construct production and trade accounts. These include production, imports of primary commodities, imports of processed commodities, exports of primary commodities and exports of processed commodities. Similar to the example in Section 2.1, we apply different approaches to the tracing of nutritional content associated with primary and processed commodities, as discussed below.

We first map primary commodity production, exports and imports to the supply categories listed above. In the case of processed commodities, while their exports and imports are reported in actual weight, their representation in FBS varies. Some of the processed commodities are converted to primary equivalents in FBS and reported aggregately with primary commodities. For instance, this is the case for flour, bread, pastry and macaroni that are reported in FBS aggregately with wheat under the 'Wheat and products' category and converted to primary equivalent. However, some processed commodities, such as wine or cream, are reported under separate processed commodity categories, though also in primary equivalents – grapes and milk respectively. To align trade data with FBS accounts, we convert processed commodities to primary equivalents using technical conversion factors (TCFs). The TCFs are compiled for 284 commodities based on FAO (2013) and Bruckner et al. (2019). Appendix S.4 reports TCF values by commodity.

For the treatment of processed commodities, we distinguish three cases—(a) Processed commodities with 1-to-1 mapping to primary commodities; (b) Processed commodities with 1-to-many mapping to primary commodities; and (c) Processed commodities mapped to the processed FBS categories. Appendix S.5 identifies such commodity categories and provides their mapping to primary

[8] A choice to adjust production instead of other categories is driven by the fact that we want to maintain food (and other) supply exactly as reported by FBS for the purposes of further comparisons.

[9] This refers to the raw non-FBS FAO data at the detailed commodity level.

commodities or processed FBS categories. In the case of 1-to-1 mapping between processed and primary commodities, first TCF conversion factors are applied and then commodities are mapped to processed trade categories.

In the case of 1-to-many mapping, the tracing of processed commodities between different primary commodities is done based on the quantity shares of processed FBS categories that correspond to primary commodities. For instance, distilled alcoholic beverages (as a processed commodity) is mapped to four primary commodities – wheat, maize, barley and rye, thus we assume in every country a combination of these primary commodities is used to produce distilled alcoholic beverages. Each of these four primary commodities is further mapped to the FBS categories that include the mix of primary and processed commodities. For instance, wheat is mapped to the FBS category wheat and products, maize to maize and products, barley to barley and products, and rye to rye and products. FBS further reports the share of commodities within each category that goes for processing, i.e. transformation into other food commodities outside a specific processed FBS category. We take corresponding volumes of commodities that go for processing for each FBS category corresponding to the primary commodity and use these as shares to allocate a processed commodity between primary commodities.

For instance, assuming that in country A there are 50 tons of wheat and products, 10 tons of maize and products, 20 tons of barley and products, and 20 tons of rye and products that go to processing, we would allocate the primary equivalent of distilled alcoholic beverages between the four primary commodities in proportions of 50%, 10%, 20% and 20% respectively.

We next adjust the primary production data so that these match the production in primary equivalents reported by the FBS. Out of 98 FBS categories, 73 are reported in primary commodity equivalents (including primary and processed commodities), while another 25 include processed commodities only. The mapping between 211 primary commodities with available production data and 73 FBS categories is provided in Appendix S.6. In most cases, primary commodity production data mapped to the FBS categories show only minor discrepancies, but for full consistency with FBS accounts we further scale the primary commodity production volumes to exactly match the FBS data.

Next, we harmonize the bilateral trade data volumes with imports and exports reported by FBS. As discussed within *Step two* above, we have collected the bilateral trade data in primary and processed commodities, as reported by FAO. However, when such data are compared with unilateral exports and imports reported by FBS, these do not match exactly. To align these two data sources, we use the FBS trade data to target unilateral country level exports and imports by FBS categories, while bilateral trade data constructed in *Step two* are used to derive the first approximation of bilateral flows. These bilateral trade flows are further balanced using a RAS technique. This is done separately for primary and processed commodities.

We finalize *Step three* of the data processing approach by constructing the FBS in primary and processed commodity equivalents for 252 primary and processed commodities—compared to the 98 standard FBS categories. Country coverage is increased to 233 countries (versus 178 countries reported in the raw FBS data). Bilateral trade is estimated and reported separately for primary commodities and processed commodities. The final part of step three consists of four *sub-steps*.

In the *first sub-step,* we address some inconsistencies within the FBS. In particular, in a number of cases the FBS reports total per capita proteins and fats supply that exceeds food supply, meaning that per 100 g of food supplied to final consumers there are more than 100 g of fats and proteins. In such cases, we proportionally downscale fats and proteins supply to match food supply. There are also cases with "0" food supply, but positive fat and protein supply. To address such cases, we set fat and protein supply to zero. Although in most cases such inconsistencies are relatively small in absolute volumes, for 2014 they constituted around 10% of all reported food supply cases. Appendix S.2 provides nutritional content data for calories, protein and fat supply by primary and processed commodities.

In the *second sub-step*, we estimate carbohydrate supply for the 98 FBS categories using the general Atwater factors (Atwater, 1916).[10] If the Atwater formula results in negative carbohydrate supply, we set it to "0". These estimates could be further refined by using the specific Atwater factors (Merrill and Watt, 1974), identified at the commodity level. However, such refinement should not substantially impact the estimates, as the differences implied by the application of general and specific Atwater factors are in general under 1%-1.5% (FAO, 2003). Apart from this, a more broad set of nutritional or environmental flows could be added to the constructed database. For instance, estimates of micronutrients with related confidence intervals could be added based on Smith et al. (2016).

In the *third sub-step*, we verify that the total fat, protein and carbohydrate supply does not exceed food supply and if this happens, we adjust carbohydrate supply to match food supply.

Finally, we align proteins, fats and carbohydrates supply with the FBS by adjusting nutritional content at the individual commodity level.

In the ***fourth step***, we provide mapping and integration of the constructed nutritional accounts to the GTAP 10 Data Base. We rely on the identified primary agriculture, processed food and service sectors that supply food to final consumers

[10] According to the Atwater system, the supply of carbohydrates per 100 g can be estimated as follows, assuming that we know the supply of calories, protein and fats for the commodity of interest (per 100 g):
*Carbohydrates = [Calories – 4*Protein – 9*Fats]/4;*

(Appendix B). Nutritional accounts constructed in *Step three* and available by country are mapped to the 141 GTAP 10 Data Base regions. We also take a three-year average of the FBS accounts and production data to smooth out variations between years.

To simplify the nutritional data tracing process by GTAP use categories, we are avoiding cases when domestic production is below exports within the same GTAP sector, thus implying re-exports at the GTAP sectoral level. And although at the commodity level we have removed cases of re-exports, when trade data are aggregated to the GTAP sectoral level, some cases when domestic production is below exports are observed. To address this issue, we increase production and other use categories by the same amount (the value of the difference between exports and domestic production observed before adjustment).[11] For most sectors, corresponding upward adjustment does not exceed 0.01% at the global level. One outstanding case is the "Other crops" sector, where the corresponding adjustment is 9%. At the same time, the share of "Other crops" output (in tons) in global food production in 2014 was only around 0.3%, therefore such adjustment does not have any significant impact on the global food production patterns. It should also be noted that this adjustment impacts only production volumes and not the food supply.

We next estimate quantities of the agricultural commodities by use categories (i.e. feed, seed, loss, other uses and food) and three supply categories – domestic supply, imported primary supply and imported processed supply. It is assumed that the shares of different use categories (in the total use) for a specific region and sector are the same for domestic and imported commodities. We also assume that imported processed commodities are not used for seed. We ensure that estimated imported primary and processed commodity volumes match the bilateral trade data constructed in *Step 2*.

The tracing of the nutritional data is treated differently for different supply categories. *First,* non-food uses (feed, seed, loss, other uses) by primary GTAP sectors are deducted from the primary commodity supply. These uses are then mapped to different GTAP sectors and reported separately. The rest (primary commodity supply less non-food uses) corresponds to the primary and processed food supply. *Second,* domestic and imported primary commodities directly consumed by households are estimated using the value shares of the GTAP Data Base (i.e. the value share of the final consumption of the corresponding commodity in the total processing and food-related use of the corresponding primary commodity). *Third,* domestic and imported primary commodities (not directly

[11] By construction, we first develop the bilateral trade data, and then keep it fixed within the next data processing steps. Such a set up implies that adjusting production and other use categories is more appropriate at this stage compared to an alternative of adjusting trade (since we aim to keep trade fixed).

consumed by households) are allocated by users using the Leontief inverse (as described in Section 2.1). *Fourth,* the allocation of commodity flows from the previous step are split into domestically consumed and exported. Exports match the bilateral trade data accounts constructed at the earlier processing step. *Fifth,* processed commodities consumed domestically are split into different use categories (feed, seed, loss, other use and food). *Sixth,* exports of the processed commodities are tracked by destinations using the bilateral trade data flows and are then allocated using the Leontief inverse (constructed for the tracing of processed commodities only) in the country of destination.

For the representation of *seed* use, we assume that this category corresponds to the self-consumption by primary agricultural sectors.[12]

In the case of *feed* use, we assume that it corresponds to the consumption of primary and processed agricultural commodities by cattle (‘ctl’), other animal products (‘oap’), raw milk (‘rmk’), wool (‘wol’) and fishing (‘fsh’) sectors.

In the case of *other uses* it is assumed that primary and processed agricultural commodities are allocated across 41 GTAP sectors (Appendix B).

In the case of *losses*, all losses that correspond to the primary supply or processing of domestic commodities and imported primary commodities are mapped to the corresponding primary sector. In the case of imported processed commodities, losses are mapped to all non-primary agricultural sectors that supply food to final consumers.

In the case of all non-food category tracing, GTAP value flows are used as shares. For instance, in the case of feed supplied by the wheat sector the following values are used as shares for allocation—value of domestic and imported wheat used by ‘ctl’, ‘oap’, ‘rmk’, ‘wol’ and ‘fsh’, value of wheat supplied (as intermediate inputs) to all food processing sectors and then used as an intermediate input (from corresponding food processing sectors) to ‘ctl’, ‘oap’, ‘rmk’, ‘wol’ and ‘fsh’ sectors.

Figure 2 provides an overview of the overall approach toward tracing of the primary domestic and imported commodities between GTAP Data Base categories.

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[12] This is a somewhat simplifying assumption, considering that in some cases primary commodities could go through some processing before being used as a seed. At the same time, looking at the cost structure value shares – both world average and country-specific – in most cases the value of self-consumption (by primary agriculture) is at least 10-20 times higher than the value of ‘ofd’ input in the corresponding primary sector, therefore it seems reasonable to assume seed is represented mostly by self-consumption. In addition, while representing a small flow in relative terms, mapping seed to processed commodities would further complicate the database construction process since it would require a more elaborate tracing procedure for this use category. We thus leave this potential improvement for future updates.

In the final database, nutritional accounts are represented in a 5-dimensional header *NUTR(TRAD_COMM, USE_CAT, SUPL_CAT, SRCR, REG)*, where:

"TRAD_COMM" represents the set of the GTAP 10 Data Base 65 traded commodities that correspond to sources of food supply;[13]

"USE_CAT" corresponds to use categories, which include TRAD_COMM, households and loss;

"SUPL_CAT" is the set of supply categories that include feed (Feed_Kt), seed (Seed_Kt), losses (Loss_Kt), other uses (Othu_Kt), food (Food_Kt), food in Terra calories (Food_Tcal), proteins (Protein_Kt), fats (Fats_Kt) and carbohydrates (Carbs_Kt); all flows apart from "Food_Tcal" are measured in Kilotons (Kt);

"SRCR" is the set of domestic ("doms") and imported (indexed by 141 regions) sources;

"REG" is the set of the GTAP 10 Data Base 141 regions.

Primary and processed imported commodities that are supplied to final consumers via agricultural or food processing sectors are mapped to the final consumption of imported commodities. Imported primary and processed agricultural commodities that are supplied to final consumers via service sectors are mapped to the final consumption of domestic services. For simulations with the static CGE model one simplifying assumption is to assume that volume flows of the constructed nutritional database change proportionally to the corresponding volume flows of the CGE model, following a specific policy implementation.

[13] "TRAD_COMM" has non-zero entries only for food-supplying sectors, which are primary agriculture and processed food.

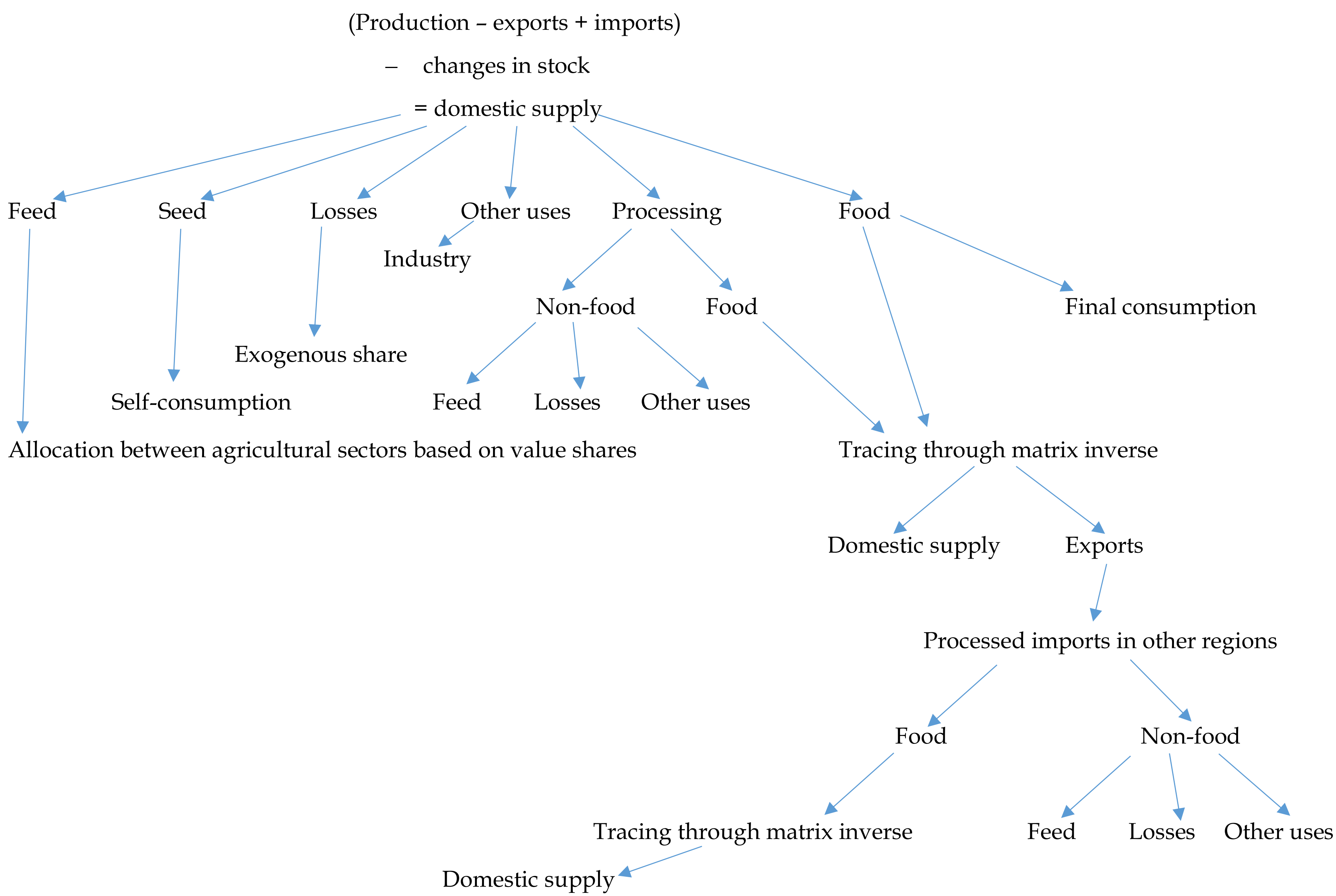

Figure 2. Overview of the approach toward tracing of the primary domestic and imported commodities between GTAP Data Base categories
Notes: Feed, seed, losses and other uses are allocated using direct mapping and/or value shares. In all other cases supply is traced using matrix inverse.

3. Overview of the constructed nutritional database

One of the indicators readily available in the developed GTAP nutritional database is the composition of calories consumed by final users. As can be seen from Figure 3, due to the differences in production, consumption and trade patterns, the sectoral composition of calories supplied to the final users differs significantly across countries. For instance, in the USA the share of calories supplied by rice (in the total value of per capita calories supplied) is around 1.5%, while in India rice accounts for 26.2% of total calories supplied. On the other hand, the share of calories that comes from sugarcane or beet is only 0.3% in China, while in the US it reaches 6.4%. In most countries and regions the processed food and beverage sector accounts for the largest share in the supplied calories, with a global average of around 25.9%.

As discussed in Section 2, in the constructed nutritional database we allocate some share of food supply to service sectors, including hotels, restaurants, educational institutions, etc. As available surveys suggest, the share of the out-of-home food consumption is exceeding 20% (in the total volume of consumed calories) in many developed countries (Saksena et al., 2018; Orfanos et al., 2009). Estimates from the GTAP nutritional database imply that the global average share of calories supplied by service sectors is around 12% for the 2014 reference year. In most countries and regions, hotels and restaurants supply the largest amount of calories compared to other service sectors.

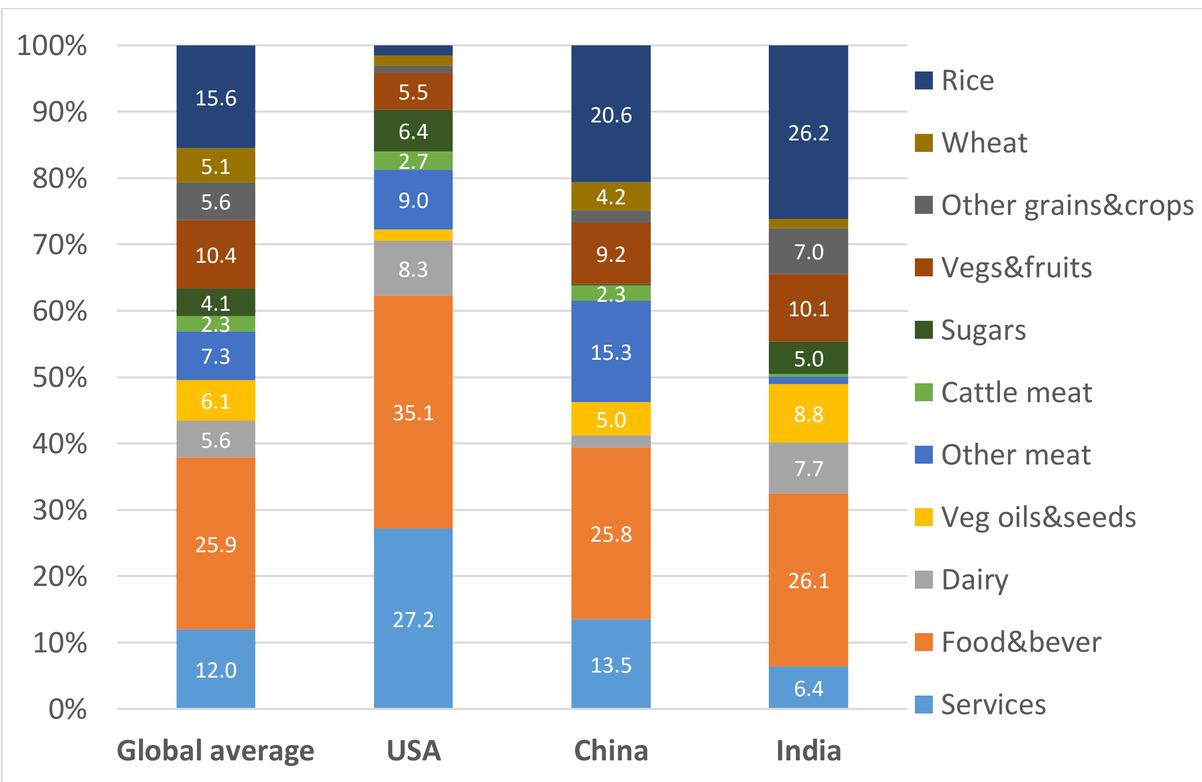

Figure 3. Distribution of calories supplied by GTAP sectors in 2014, % (global average and selected countries)

Source: own estimates.

Comparisons between shares of calories supplied by the service sectors implied by the GTAP nutritional database with the shares of out-of-home food consumption from the available surveys for selected countries suggest a relatively close match, considering differences in reference years and methodology (Figure 4).

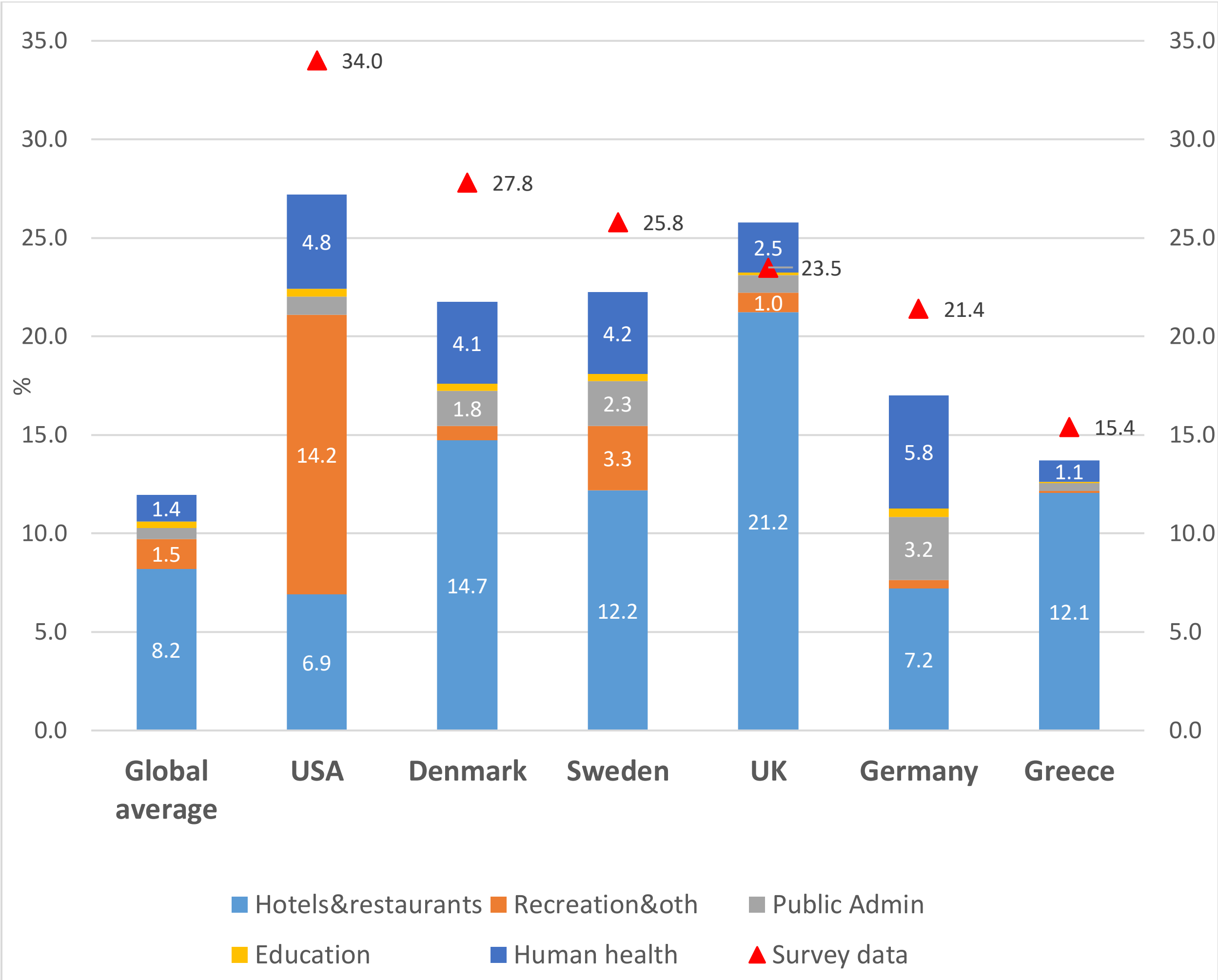

Figure 4. Share of calories supplied by GTAP service sectors in 2014, % of total calories supplied (selected countries)

Source: developed by author using GTAP nutritional database, Saksena et al. (2018) and Orfanos et al., (2009).

Due to the differences in commodity composition of the primary and processed GTAP agricultural sectors, variations in the caloric content of commodities (per unit of weight) and differences in prices of commodities across regions, there is a high variation in calories supplied per 1 USD (Figure 5). While in the case of fish, bovine meat and beverages less than 300 kcal can be purchased per 1 USD (global weighted average value), in the case of commodities like raw sugar, wheat, rice and other grains, each dollar can purchase over 6000 kcal (world weighted average value).

From the modelling point of view, an important characteristic of the constructed database is variation in calories supplied per 1 USD for a specific commodity group across regions. Error bars on figure 5, indicate such spread across 10 aggregate regions (Appendix C). In many commodity cases, the corresponding spread across regions is 3-4 times or higher.

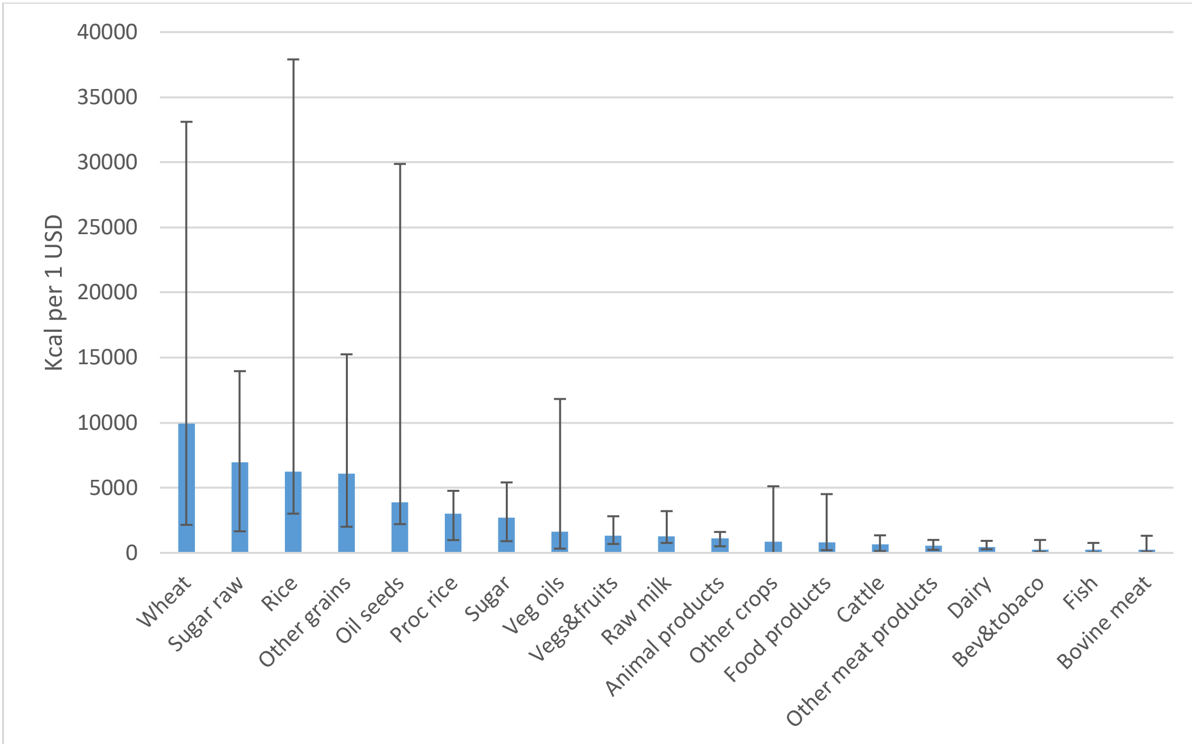

Figure 5. Kcal per 1 USD from domestic commodities supplied by selected GTAP sectors in 2014 (world consumption-weighted average values)

Notes: Values of final consumption are used to estimate the weighted average. Error bars indicate the minimum and maximum value across ten aggregate regions: Oceania, East Asia, South East Asia, South Asia, North America, Latin America, EU-27, Middle East and North Africa, Sub Saharan Africa and Rest of the World. Corresponding regional mapping is provided in Appendix C.
Source: Own calculation.

Corresponding variations in domestically supplied calories that can be purchased per 1 USD are even larger across individual countries, especially for the sectors that consist of many heterogeneous commodities, like vegetables fruits and nuts (Figure 6), and processed food (Figure 7). Some of the corresponding variations can be explained by variations in the sectoral commodity composition structure and differences in prices of the same commodity across regions.

In the case of processed food, part of the observed variation could be also explained by differences in supply chains across countries. Producers in low income countries spend less on marketing, packaging and branding compared to suppliers in high income economies, which results in overall lower value added and service expenditure shares. As a result, the caloric supply per USD tends to be higher in lower income countries.

At the same time, some of the observed differences are coming from the merging of GTAP value flows and FAO-based quantities of production and consumption (nutritional information). Although such inconsistencies have been partially addressed via FAO-based agricultural production targeting, in some commodity and country cases, due to the necessity to preserve the GTAP trade data, it was impossible to exactly reach the FAO-based targets (Chepeliev, 2020). As a result, GTAP-implied commodity prices still show large deviations from the FAO-reported commodity prices, though considerably smaller than in the standard GTAP 10A Data Base (Aguiar et al, 2019).

Even higher variations in calories per 1 USD are observed for imported commodities. In many cases these large variations are caused by differences between FAO and GTAP values of trade.

While nutritional accounts are based on the FAO-reported quantities of traded food, trade values in the GTAP Data Base are constructed based on the reconciled UN Comtrade Database (Aguiar et al., 2019). Therefore, one particular improvement of the constructed GTAP nutritional database would include further revision of production and trade accounts of the standard GTAP Data Base to bring it more in line with the FAO value and quantity flows.

One particular concern of large variations in nutrient supply per USD across regions is associated with potential switching of imports between sources with large differences in nutrient content, as this might result in substantial changes in nutritional (per capita) supply for the importing region following the policy experiment. This potential issue becomes even more important under large shocks or over the longer time horizon (i.e. in dynamic simulations), when more substantial structural adjustments might take place. Addressing this issue might require adjustments in nutrition factors post-simulation or between periods.

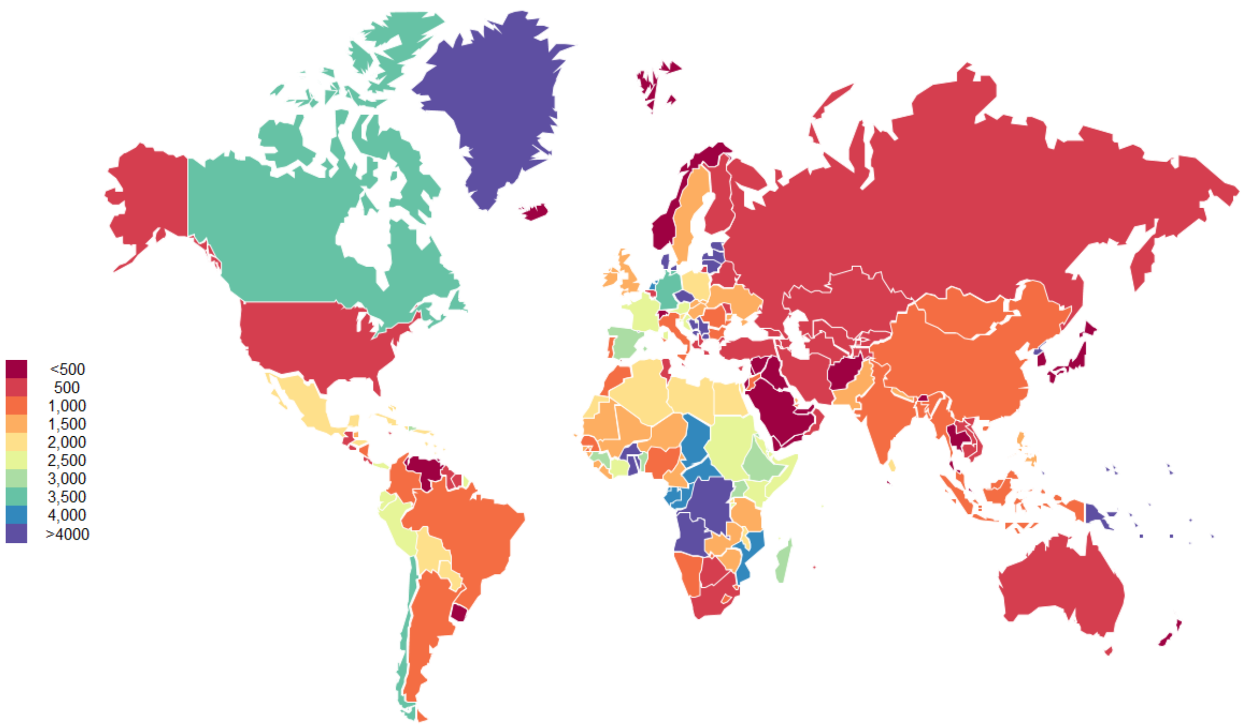

Figure 6. Kcal per 1 USD from domestic commodities supplied by the vegetables, fruits and nuts sector ('v_f') in 2014

Source: Estimated by author.

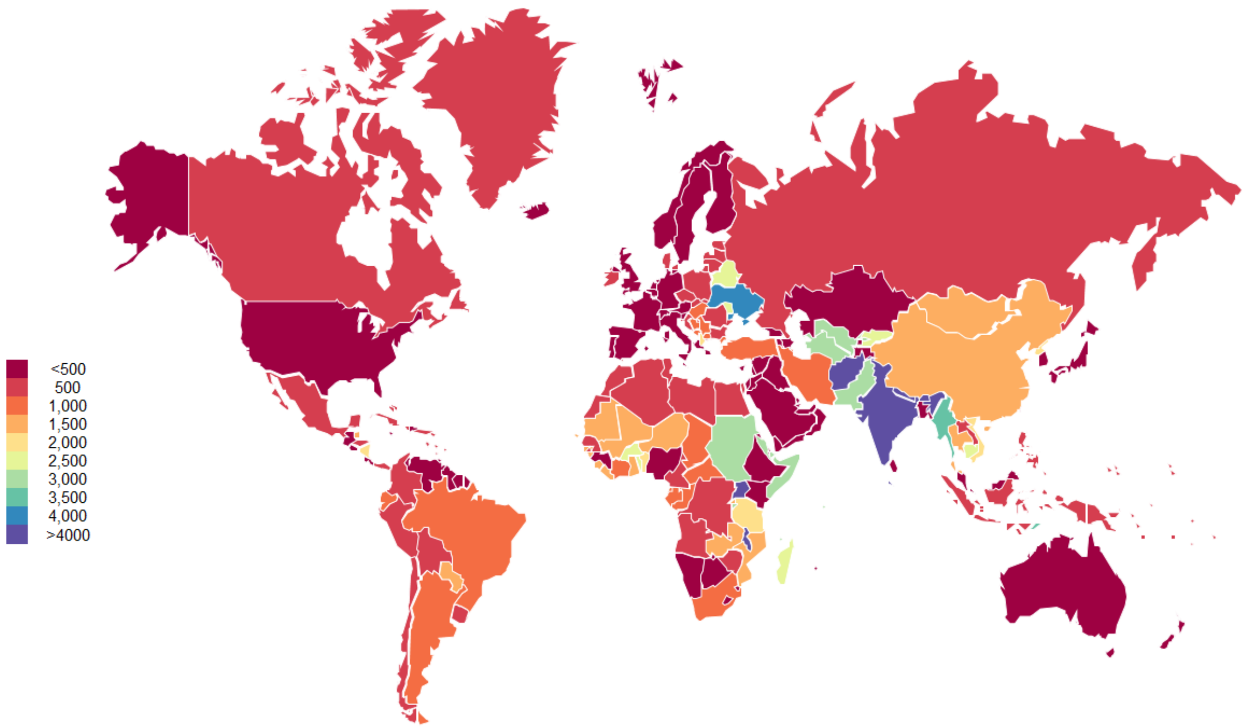

Figure 7. Kcal per 1 USD from domestic commodities supplied by the processed food sector ('ofd') in 2014
Source: Estimated by author.

4. Illustrative application

In this section, we showcase how the constructed nutritional database can be linked to the standard GTAPv7 model (Corong et al., 2017) for the assessment of nutritional outcomes of various policies. For illustrative purposes, we aggregate the GTAP 10A Data Base to 3 aggregate regions and 25 commodities (Appendix D). The 2007 reference year is used for the application. Grouping of countries into aggregate regions is based on the per capita calorie consumption: high ("HIGH") with daily per capita calories consumption above 3000 kcal, medium "MED" with daily consumption between 2500 kcal and 3000 kcal and low ("LOW") with daily consumption below 2500 kcal. The policy simulation includes elimination of import tariffs and subsidies on agricultural and food commodities by all three aggregate regions.[14] Changes in the GTAP nutritional database flows are linked to the quantity changes reported by the standard GTAPv7 model (e.g. changes in demand for domestic and imported commodities by activities and final users, changes in domestic sales, etc.). This is a simplified approach for tracking nutritional flows, since it does not account for changes in the regional mix of imported processed food used as intermediate inputs, but assumes that the corresponding mix is fixed.[15]

In terms of the trade patterns, the "HIGH" region is importing 20% of their food (in terms of energy content – Kcal), which is equivalent to around 670 Kcal per capita per day, though almost 75% of these imported Kcal are associated with trade within the "HIGH" region (Figure 8). Both "LOW" and "MED" regions import much lower shares of their Kcal compared to the "HIGH"

[14] Both between- and within -region tariffs are eliminated in this experiment.

[15] This approach though does account for changes in the regional mix of imported primary and processed commodities that are consumed directly by households.

region – 12% in both cases, at the same time the majority of these imports are coming from the "HIGH" region (Figure 2).

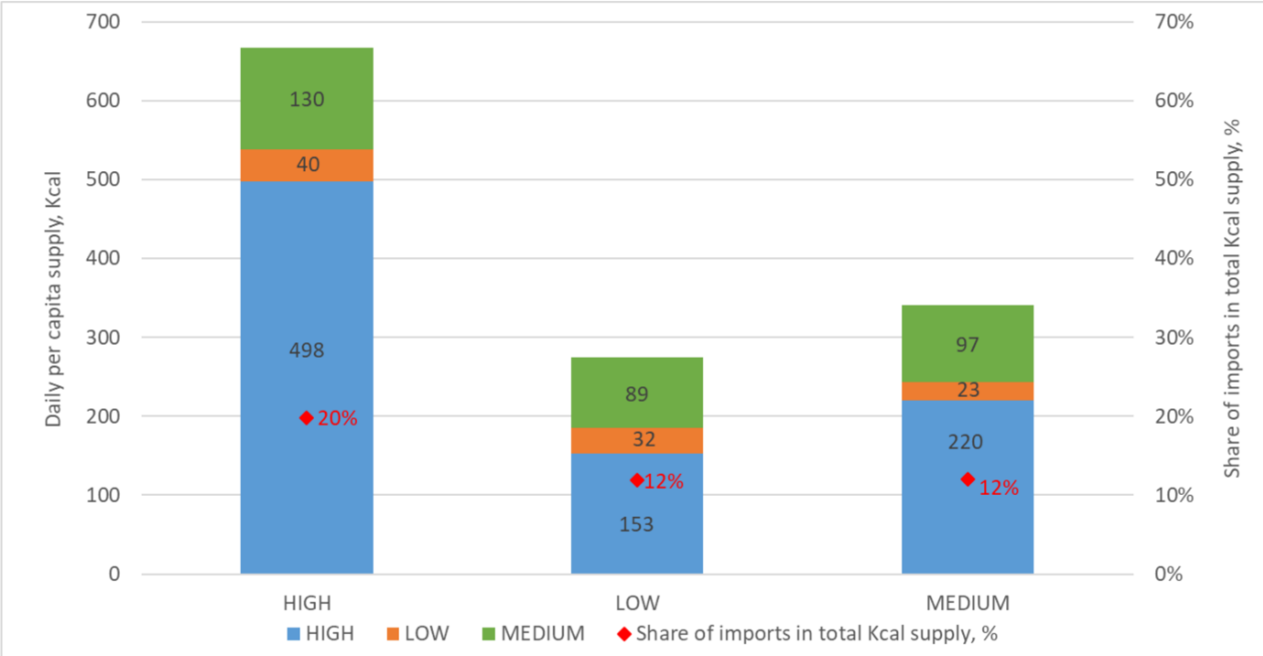

Figure 8. Distribution of Kcal per capita per day embodied into imports by aggregate regions in 2007
Notes: Numbers within the color bars indicate the value of Kcal supply through imported commodities from each of the destinations and consumed in the corresponding receiving region (identified on the horizontal axis). Red diamonds indicate share of imports in total Kcal supply and correspond to the secondary vertical axis.
Source: Estimated by author.

Import tariffs that are eliminated within the implemented policy experiment generally range between 5%-10%, but in some cases exceed 25% – e.g. other grains imports by the "HIGH" region, vegetable oil imports by the "LOW" region and processed rice imports by the "MED" region (Figure 9). In many sectors with relatively higher tariffs (e.g. above 15%) the share of imports in total kcal consumption of the corresponding commodity is at least 20% (Figure 9). For instance, this is the case for other grains, oil seeds and sugar imports by the "HIGH" region, vegetable oils and beverages imports by the "LOW" region and cattle meat and beverages imports by the "MED" region.

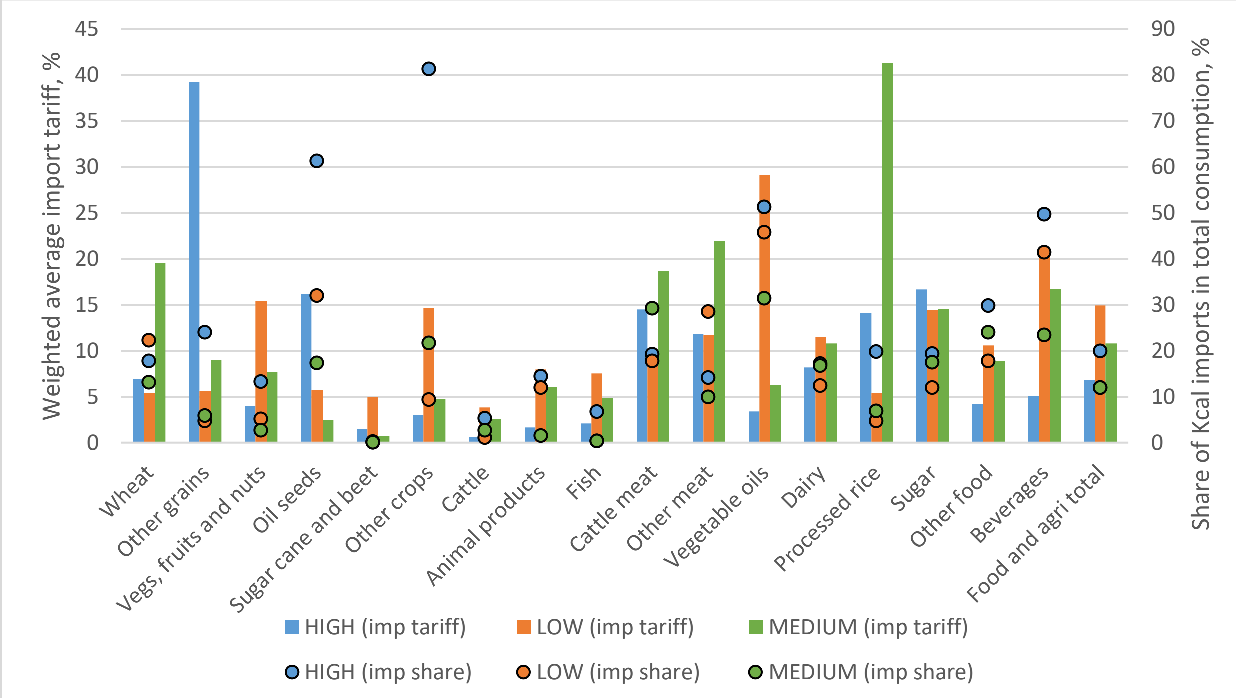

Figure 9. Import tariffs and import shares for selected agricultural and food sectors in 2007, %
Source: Estimated by author.

Simulation results suggest that with elimination of import tariffs, kcal food supply increases in all regions ranging from +1.1% in the "LOW" and "MED" regions to +1.6% in the "HIGH" region (Figure 10). As in the reference year, most imported kcal in all regions were sourced from the "HIGH" region (Figure 8), most of the observed increases in imports are also associated with this region. In general, overall increases in kcal supply are rather moderate in absolute terms, for instance the "LOW" region consumes an additional 26 kcal per person per day, while the "HIGH" region increases daily per capita consumption by around 55 kcal.

Protein, fats and carbohydrates supply are also increasing (Figure 10), though changes are more heterogeneous across regional aggregations, depending on the composition of reference year imports and tariff levels. For instance, a larger increase in protein supply in "MED" can be explained by a substantial increase in the imports of rice and other food (Figure 11). Both commodities were substantially protected by the import tariffs in the reference year, with a weighted average rate of 41% and 9% respectively (Figure 9). "LOW" region experiences a relatively large increase in fats supply, driven by the rising imports of vegetable oils (Figure 11) that initially were facing an import tariff of over 29% (Figure 9). In the case of carbohydrates in "MED" region, we observe almost no change relative to the reference case, as increasing imports of other food and rice from "HIGH" are overweighed by reductions in the domestic supply of rice and wheat (Figure 10).

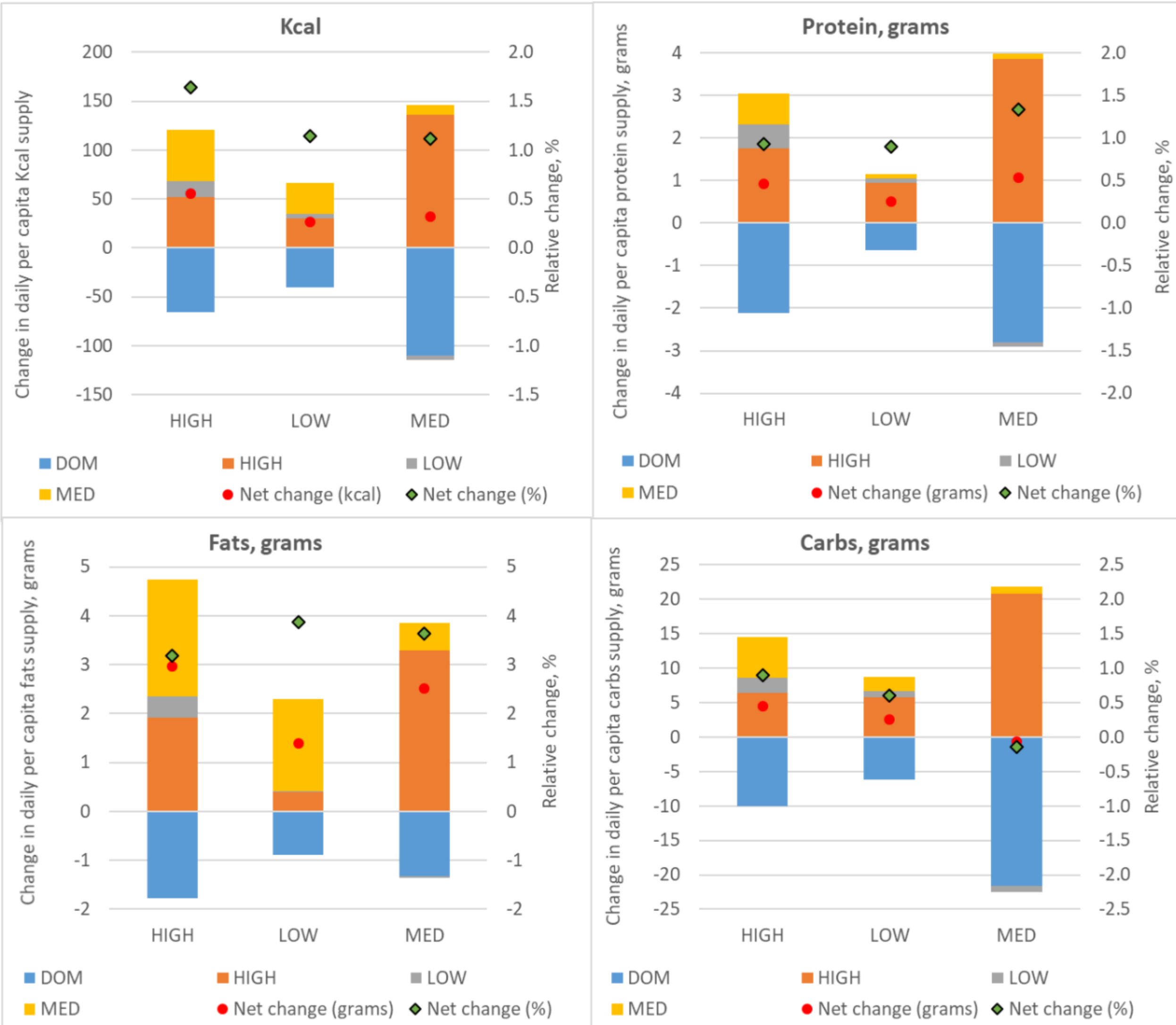

Figure 10. Change in daily per capita nutritional supply following import tariff elimination
Source: Estimated by author.

Figure 11 reports some other selected commodities that are experiencing substantial changes in total kcal supply. In all regions, we can see that there is a substantial increase in imports of the other food commodity group, which includes a diverse set of processed food items and constitutes a large share of the total food supply (in terms of kcal) – ranging from 18% in “LOW” to almost 26% in “HIGH” region.

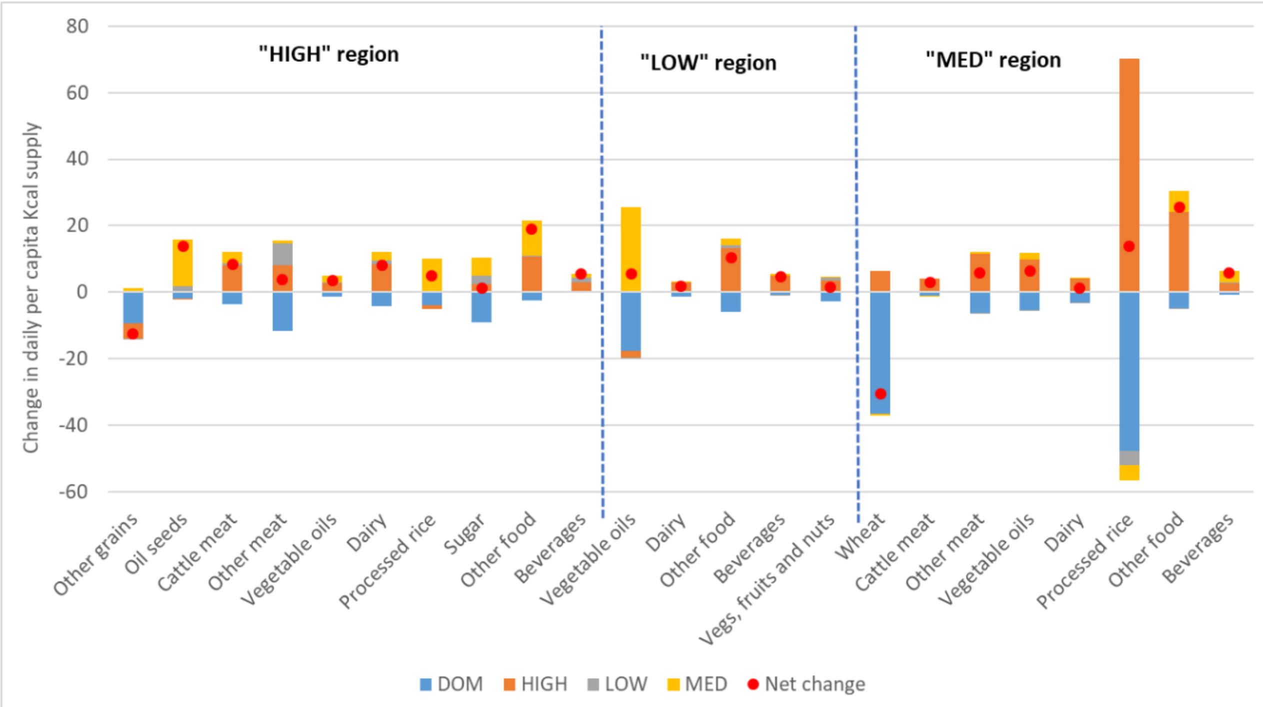

Figure 11. Change in the daily per capita kcal supply by sources for selected commodities

Notes: Blue dotted lines separate estimates for different food consumption regions. Colors of stacked bars correspond to different sources of food supply, i.e. domestic or imported from one of the three aggregate regions identified in the sample application. For each reported sector, a net change in daily per capita kcal supply in identified by the red dot. Selected sectors are reported in the figure.

Source: Estimated by author.

One important feature that is incorporated into the constructed database is differentiation of nutritional content across bilateral trade flows. As a result, switching between different sources of imports changes both volume and nutritional composition of imported food. To illustrate this point for the case of the other food sector, we implement a decomposition of changes in imported kcal and nutrients across regions within the illustrative application. Two channels are distinguished: scale effect (estimates an outcome under the assumption of uniform nutritional content across sources) and composition effect (represents contribution of the variation in nutritional content across sources). Results of the corresponding decomposition are reported in Appendix E.

As one can see from these decomposition results, even in this very aggregate regional representation, where much heterogeneity across regions has been smoothed out, the composition effect plays a relatively important role in explaining the results, on average contributing up to 9%-12%. In some particular cases, like fats in HIGH region, the composition effect accounts for over 30% of the observed outcome. One would expect a much larger contribution of the composition effect at the individual country level, where the food and nutritional content of the bilateral trade flows is much more heterogeneous than in this highly aggregated example. The latter point further highlights the potential importance of accounting for changes in the regional mix of imported processed food used as intermediate inputs, when tracking nutritional outcomes. As noted above, the latter is assumed to be fixed in this illustrative application.

5. Discussion and conclusions

With a wide range of implications for welfare, food security, land use, trade and environment, food-related policies represent a complex issue that should be assessed with a set of modelling tools that properly account for all the involved interactions. With post-farmgate food value chains making up most of consumer expenditures worldwide (Yi et al., 2021), it is extremely important to track the nutritional content beyond the post-farm supply chains. Due to the complete coverage of economic flows, CGE models, as opposed to a partial equilibrium modelling approach, provide much better opportunities to address this issue by explicitly representing food supply in processing and service sectors. At the same time, as of today, there have not been many applications of these models, with an explicit representation of nutritional accounts. Those that are available have some major limitations in terms of the consistent representation of nutritional data flows, as discussed in the Introduction, and are not publicly available to the broad modelling community.

In this paper, we attempt to address some of the limitations identified in the literature and develop an approach toward incorporation of nutritional accounts into the GTAP 10 Data Base with FAO-based agricultural production targeting (Chepeliev, 2020). We rely on the FAO FBS data and nutritive indicators to estimate the nutritional content of primary commodities and derived commodities represented in primary commodity equivalent within FBS. Calories, fats, proteins and carbohydrates are estimated and reported. We further identify use categories that account for food, feed, seed, losses and other uses. Food supply is attributed to GTAP primary commodity sectors, food processing sectors and selected service sectors. To trace nutritional data by GTAP sectors, we construct the Leontief inverse, operating only over those sectors (and uses) that supply food. Different Leontief inverses are used for tracing domestic food supply, exported food and imported food. We showcase an application of the developed nutritional database by linking it to the GTAP CGE model and providing an assessment of a trade policy shock on the nutritional outcomes.

While providing a consistent accounting of the food and non-food quantity flows within the CGE modelling approach, there are several future improvements and modifications that the current framework developed could benefit from.

First, although being based on the special release of the GTAP Data Base with FAO-based agricultural production targeting (Chepeliev, 2020), developed nutritional accounts would benefit from further revision of production and trade accounts of the standard GTAP Data Base to bring them more in line with the FAO value and quantity flows.

Second, some use accounts in the constructed database could be represented in more detail, as well as more explicitly traced throughout the value chain. In particular, this includes better representation of the food loss and waste, which in the current version of the database is reported as a single category and thus not allocated between different commodity transformation stages (e.g. processing, transportation, storage, etc.).

Third, for the case of countries not reported in the FAO FBS – mostly small agricultural producers – some assumptions were made to come up with nutritional accounts data (based on the mapping to the 'like' countries). Upon availability of the country-specific nutritional information, these assumptions could be revised.

Fourth, the current version of the database reports supply of kcal, fats, proteins and carbohydrates, but does not report supply of micronutrients. Inclusion of the latter category could improve the representation of the developed nutritional accounts.

Fifth, while in the current paper we focus on the representation of nutritional accounts, an important future extension includes merging this development with a more complete tracing of biomass flows. Such extension would allow analysis of a much broader set of environmental, food and agriculture-related issues, such as bioenergy-related policies, water use and land use activities, as well as provide a more complete GHG emissions accounting framework.

Finally, while the developed database construction approach can be applied in the context of dynamic simulations (with nutritional accounting updated between simulated years), the current implementation was performed in the static modelling framework and needs to be further tested in dynamic modelling applications. The latter would require implementing the developed tracing approach in-between simulated time steps, accounting for possible changes in production and consumption structures over time. In addition, one might also consider implementing adjustments to the nutritional content over time, which could be driven by a number of factors, including expected changes in the composition of production within broad GTAP sectors (e.g. changing mix of vegetables and fruits production).

Data availability

Two simulation archives are provided in the supplementary materials that accompany this paper and correspond to the simulations discussed in Section 4: RunGTAP simulation archive ("foodsubs.zip") and a standalone nutritional outcomes assessment program "fbsest.zip". The latter reads in the outcomes of the RunGTAP simulations and provides an assessment of the nutritional impacts. "Readme.txt" file in the "fbsest.zip" archive provides an overview of the simulation steps that should be implemented to replicate the results reported in this section. The fully disaggregated version of the GTAP 10 nutritional database is available to the GTAP Board Members, contributors and subscribers. Starting from GTAP 11, GTAP nutritional database would be distributed in a GTAPAgg2 and Flexagg aggregation formats.

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Appendix A. Stylized single country example of the nutritional accounts incorporation to the input-output framework

Table A.1. Matrix of imports, USD

	Agriculture	Food	Industry	Services	Final cons.	**Total**
Agriculture	0.1	0.8	0.1	0.1	0.7	**1.8**
Processed food	0.1	1.0	0.2	0.6	5.3	**7.2**
Industry	0.3	0.6	25.3	8.9	14.6	**49.7**
Services	0.1	0.4	2.8	9.0	2.4	**14.7**
Total	**0.6**	**2.8**	**28.4**	**18.6**	**23.0**	

Table A.2. Intermediate consumption shares corresponding to the food-related output for imported processed commodities tracing

	Agriculture	Food	Industry	Services	Final cons.
Agriculture	0	0	0	0	0
Processed food	0	0.225	0	0.017	0
Industry	0	0	0	0	0
Services	0	0	0	0	0

Notes: numbers reported in the table are rounded to the third decimal point.

Table A.3. Indicators for the tracing of imported processed food

	Total supply, grams	Grams/USD of final consumption	Total grams to final consumption
Agriculture	-	-	-
Processed food	87.0	11.0	62.7
Industry	-	-	-
Services	52.2	0.6	76.4
Final consumption (direct)	460.9	-	460.9
Total	**600.0**	**-**	**600.0**

Notes: numbers reported in the table are rounded to the first decimal point.

Appendix B. Mapping between GTAP 10 Data Base sectors and food supplying instances

No.	Code	Description	Primary agriculture	Processed food	Food-supplying service sectors	Other uses
1	pdr	Paddy rice	+			
2	wht	Wheat	+			
3	gro	Other grains	+			
4	v_f	Vegetables, fruit and nuts	+			
5	osd	Oil Seeds	+			
6	c_b	Cane and beet	+			
7	pfb	Fiber crops				+
8	ocr	Other Crops	+			
9	ctl	Cattle	+			
10	oap	Other Animal Products	+			
11	rmk	Raw milk	+			
12	wol	Wool				+
13	frs	Forestry				+
14	fsh	Fishing	+			
15	coa	Coal mining				+
16	oil	Extraction of crude petroleum				+
17	gas	Extraction of natural gas				+
18	oxt	Other mining extraction				+
19	cmt	Cattle meat		+		
20	omt	Other meat		+		
21	vol	Vegetable oils		+		
22	mil	Milk: dairy products		+		
23	pcr	Processed rice		+		
24	sgr	Sugar and molasses		+		
25	ofd	Other food		+		
26	b_t	Beverages and tobacco products		+		
27	tex	Textiles				+
28	wap	Wearing apparel				+
29	lea	Leather and related products				+
30	lum	Lumber				+
31	ppp	Paper and paper products				+
32	p_c	Petroleum and coke				+
33	chm	Chemicals and chemical products				+
34	bph	Pharmaceuticals products				+
35	rpp	Rubber and plastics products				+
36	nmm	Other non-metallic mineral products				+
37	i_s	Iron and steel				+

No.	Code	Description	Primary agriculture	Processed food	Food-supplying service sectors	Other uses
38	nfm	Non-ferrous metals				+
39	fmp	Fabricated metal products				+
40	ele	Computer, electronic and optical products				+
41	eeq	Electrical equipment				+
42	ome	Machinery and equipment n.e.c.				+
43	mvh	Motor vehicles, trailers and semi-trailers				+
44	otn	Other transport equipment				+
45	omf	Other Manufacturing				+
46	ely	Electricity, steam and air conditioning supply				+
47	gdt	Gas manufacture, distribution				+
48	wtr	Water supply				+
49	cns	Construction				+
50	trd	Wholesale and retail trade				+
51	afs	Accommodation, food and service activities			+	
52	otp	Land transport and transport via pipelines				+
53	wtp	Water transport				+
54	atp	Air transport				+
55	whs	Warehousing and support activities				+
56	cmn	Information and communication				+
57	ofi	Other financial intermediation				+
58	ins	Insurance				+
59	rsa	Real estate activities				+
60	obs	Other business services nec				+
61	ros	Recreation and other services			+	
62	osg	Other services (government)			+	
63	edu	Education			+	
64	hht	Human health and social work			+	
65	dwe	Dwellings				+
	Total number of sectors		**11**	**8**	**5**	**41**

Source: Developed by author based on GTAP (2020).

Appendix C. Regional aggregation used for reporting in Section 3

No.	Aggregate region	GTAP 10 regions
1.	Oceania	Australia (aus), New Zealand (nzl), Rest of Oceania (xoc)
2.	East Asia	China (chn), Hong Kong (hkg), Japan (jpn), Korea (kor), Mongolia (mng), Taiwan (twn), Rest of East Asia (xea), Brunei Darussalam (brn)
3.	South East Asia	Cambodia (khm), Indonesia (idn), Lao People's Democratic Republic (lao), Malaysia (mys), Philippines (phl), Singapore (sgp), Thailand (tha), Viet Nam (vnm), Rest of Southeast Asia (xse)
4.	South Asia	Bangladesh (bgd), India (ind), Nepal (npl), Pakistan (pak), Sri Lanka (lka), Rest of South Asia (xsa)
5.	North America	Canada (can), United States of America (usa), Mexico (mex), Rest of North America (xna)
6.	Latin America	Argentina (arg), Bolivia (bol), Brazil (bra), Chile (chl), Colombia (col), Ecuador (ecu), Paraguay (pry), Peru (per), Uruguay (ury), Venezuela (ven), Rest of South America (xsm), Costa Rica (cri), Guatemala (gtm), Honduras (hnd), Nicaragua (nic), Panama (pan), El Salvador (slv), Rest of Central America (xca), Dominican Republic (dom), Jamaica (jam), Puerto Rico (pri), Trinidad and Tobago (tto), Rest of Caribbean (xcb)
7.	EU-27	Austria (aut), Belgium (bel), Bulgaria (bgr), Croatia (hrv), Cyprus (cyp), Czech Republic (cze), Denmark (dnk), Estonia (est), Finland (fin), France (fra), Germany (deu), Greece (grc), Hungary (hun), Ireland (irl), Italy (ita), Latvia (lva), Lithuania (ltu), Luxembourg (lux), Malta (mlt), Netherlands (nld), Poland (pol), Portugal (prt), Romania (rou), Slovakia (svk), Slovenia (svn), Spain (esp), Sweden (swe)
8.	Middle East and North Africa	Bahrain (bhr), Iran Islamic Republic of (irn), Israel (isr), Jordan (jor), Kuwait (kwt), Oman (omn), Qatar (qat), Saudi Arabia (sau), Turkey (tur), United Arab Emirates (are), Rest of Western Asia (xws), Egypt (egy), Morocco (mar), Tunisia (tun), Rest of North Africa (xnf)
9.	Sub Saharan Africa	Benin (ben), Burkina Faso (bfa), Cameroon (cmr), Cote d'Ivoire (civ), Ghana (gha), Guinea (gin), Nigeria (nga), Senegal (sen), Togo (tgo), Rest of Western Africa (xwf), Central Africa (xcf), South Central Africa (xac), Ethiopia (eth), Kenya (ken), Madagascar (mdg), Malawi (mwi), Mauritius (mus), Mozambique (moz), Rwanda (rwa), Tanzania (tza), Uganda (uga), Zambia (zmb), Zimbabwe (zwe), Rest of Eastern Africa (xec), Botswana (bwa), Namibia (nam), South Africa (zaf), Rest of South African Customs (xsc)
10.	Rest of World	Switzerland (che), Norway (nor), Rest of EFTA (xef), Albania (alb), Belarus (blr), Russian Federation (rus), Ukraine (ukr), Rest of Eastern Europe (xee), Rest of Europe (xer), Kazakhstan (kaz), Kyrgyzstan (kgz), Tajikistan (tjk), Rest of Former Soviet Union (xsu), Armenia (arm), Azerbaijan (aze), Georgia (geo), Rest of the World (xtw)

Source: Developed by author.

Appendix D. Regional and sectoral aggregation used for the policy simulation

Table D.1. Regional aggregation

No.	Aggregate region code	Aggregate region description	GTAP 10 regions
1.	HIGH	Countries with daily per capita food consumption > 3000 kcal	Australia (aus), New Zealand (nzl), Hong Kong (hkg), Korea (kor), Singapore (sgp), Canada (can), United States of America (usa), Mexico (mex), Argentina (arg), Brazil (bra), Austria (aut), Belgium (bel), Croatia (hrv), Czech Republic (cze), Denmark (dnk), Estonia (est), Finland (fin), France (fra), Germany (deu), Greece (grc), Hungary (hun), Ireland (irl), Italy (ita), Latvia (lva), Lithuania (ltu), Luxembourg (lux), Malta (mlt), Netherlands (nld), Poland (pol), Portugal (prt), Romania (rou), Slovenia (svn), Spain (esp), Sweden (swe), United Kingdom (gbr), Switzerland (che), Norway (nor), Rest of EFTA (xef), Albania (alb), Belarus (blr), Russian Federation (rus), Ukraine (ukr), Rest of Europe (xer), Kazakhstan (kaz), Azerbaijan (aze), Georgia (geo), Bahrain (bhr), Iran Islamic Republic of (irn), Israel (isr), Jordan (jor), Kuwait (kwt), Qatar (qat), Saudi Arabia (sau), Turkey (tur), United Arab Emirates (are), Egypt (egy), Morocco (mar), Tunisia (tun), Rest of North Africa (xnf)
2.	MED	Countries with daily per capita food consumption 2500-3000 kcal	China (chn), Japan (jpn), Taiwan (twn), Brunei Darussalam (brn), Indonesia (idn), Malaysia (mys), Philippines (phl), Thailand (tha), Viet Nam (vnm), Chile (chl), Colombia (col), Paraguay (pry), Uruguay (ury), Venezuela (ven), Rest of South America (xsm), Costa Rica (cri), Honduras (hnd), El Salvador (slv), Rest of Central America (xca), Jamaica (jam), Puerto Rico (pri), Trinidad and Tobago (tto), Caribbean (xcb), Bulgaria (bgr), Cyprus (cyp), Slovakia (svk), Rest of Eastern Europe (xee), Kyrgyzstan (kgz), Rest of Former Soviet Union (xsu), Armenia (arm), Oman (omn), Benin (ben), Burkina Faso (bfa), Cote d'Ivoire (civ), Ghana (gha), Nigeria (nga), Mauritius (mus), Rest of Eastern Africa (xec), South Africa (zaf)
3.	LOW	Countries with daily per capita food consumption < 2500 kcal	Rest of Oceania (xoc), Mongolia (mng), Rest of East Asia (xea), Cambodia (khm), Lao People's Democratic Republ (lao), Rest of Southeast Asia (xse), Bangladesh (bgd), India (ind), Nepal (npl), Pakistan (pak), Sri Lanka (lka), Rest of South Asia (xsa), Rest of North America (xna), Bolivia (bol), Ecuador (ecu), Peru (per), Guatemala (gtm), Nicaragua (nic), Panama (pan), Dominican Republic (dom), Tajikistan (tjk), Rest of Western Asia (xws), Cameroon (cmr), Guinea (gin), Senegal (sen), Togo (tgo), Rest of Western Africa (xwf), Central Africa (xcf), South Central Africa (xac), Ethiopia (eth), Kenya (ken), Madagascar (mdg), Malawi (mwi), Mozambique (moz), Rwanda (rwa), Tanzania (tza), Uganda (uga), Zambia (zmb), Zimbabwe (zwe),

No.	Aggregate region code	Aggregate region description	GTAP 10 regions
			Botswana (bwa), Namibia (nam), Rest of South African Customs (xsc), Rest of the World (xtw)

Source: Developed by author.

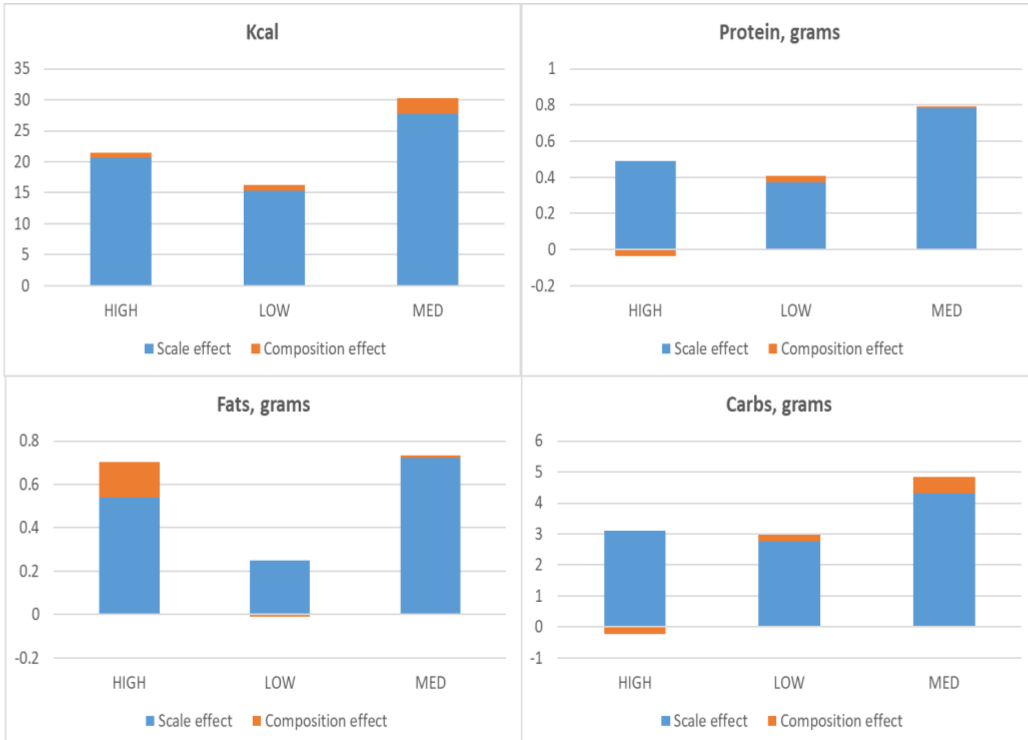
Table D.2. Sectoral aggregation

No.	Aggregate sector code	Aggregate sector description	GTAP 10 sectors
1.	pdr	Paddy rice	Paddy rice (pdr)
2.	wht	Wheat	Wheat (wht)
3.	gro	Cereal grains nec	Cereal grains nec (gro)
4.	v_f	Vegetables, fruit, nuts	Vegetables, fruit, nuts (v_f)
5.	osd	Oil seeds	Oil seeds (osd)
6.	c_b	Sugar cane, sugar beet	Sugar cane, sugar beet (c_b)
7.	xagr	Other agriculture	Plant-based fibers (pfb), Wool, silk-worm cocoons (wol), Forestry (frs)
8.	ocr	Crops nec	Crops nec (ocr)
9.	ctl	Bovine cattle, sheep and goats	Bovine cattle, sheep and goats (ctl)
10.	oap	Animal products nec	Animal products nec (oap)
11.	rmk	Raw milk	Raw milk (rmk)
12.	fsh	Fishing	Fishing (fsh)
13.	xtr	Extraction	Coal (coa), Oil (oil), Gas (gas), Minerals nec (oxt)
14.	cmt	Bovine meat products	Bovine meat products (cmt)
15.	omt	Meat products nec	Meat products nec (omt)
16.	vol	Vegetable oils and fats	Vegetable oils and fats (vol)
17.	mil	Dairy products	Dairy products (mil)
18.	pcr	Processed rice	Processed rice (pcr)
19.	sgr	Sugar	Sugar (gr)
20.	ofd	Food products nec	Food products nec (ofd)
21.	b_t	Beverages and tobacco products	Beverages and tobacco products (b_t)
22.	xmn	Other manufacturing	Textiles (tex), Wearing apparel (wap), Leather products (lea), Wood products (lum), Paper products, publishing (ppp), Petroleum, coal products (p_c), Chemical products (chm), Basic pharmaceutical products (bph), Rubber and plastic products (rpp), Mineral products nec (nmm), Ferrous metals (i_s), Metals nec (nfm), Metal products (fmp), Computer, electronic and optic (ele), Electrical equipment (eeq), Machinery and equipment nec (ome), Motor vehicles and parts (mvh), Transport equipment nec (otn), Manufactures nec (omf)
23.	util	Utilities	Electricity (ely), Gas manufacture, distribution (gdt), Water (wtr)

No.	Aggregate sector code	Aggregate sector description	GTAP 10 sectors
24.	xsrv	Other services	Construction (cns), Trade (trd), Transport nec (otp), Water transport (wtp), Air transport (atp), Warehousing and support activities (whs), Communication (cmn), Financial services nec (ofi), Insurance (ins), Real estate activities (rsa), Business services nec (obs), Dwellings (dwe)
25.	fsrv	Food supplying services	Accommodation, Food and services (afs), Recreational and other service (ros), Public Administration and defense (osg), Education (edu), Human health and social work activities (hht)

Source: Developed by author.

Appendix E. Decomposition of nutritional imports of other food sector



Notes: Scale effect corresponds to the case of uniform nutritional content across sources (regions). Composition effect represents contribution of the variation in nutritional content across sources (regions).