

Supporting Information for

Cross-border exposure of Canada's fruit and vegetable supply to future weather extremes

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Introduction

In this section, we undertake a detailed explanation of food flows, encompassing 18 fruits and 16 vegetables over the period from 2010 to 2022. This covers all 10 Canadian provinces, with data accounting for domestic production, interprovincial flows, and international flows. The scope of our data is notably broad, spanning imports from 151 countries, along with disaggregated data for the 53 US states and territories. A distinguishing feature of our dataset is its granularity at the sub-national level for Canada and its main trading partner, the USA, which provides insights into specific flows from individual US states.

In addition to the supporting information, figures and tables used for the development of food flows, this document also provides all supporting figures for the key results pertaining to the future extreme weather exposure.

Text S1. Development of food flows

While a significant body of research exists on national level food flows aimed at assessing the sustainability and resilience of food supply chains (Davis et al., 2021; Kastner et al., 2021), only a few focus at sub-national scales. Lin et al., (2019) and Karakoc et al., (2022) measured food flows between US counties using a complex and extensive modelling approach. Dalin et al., (2014) used an economic model and linear optimization approach to estimate interprovincial flows for China. Harris et al., (2020) also used a linear optimization approach to estimate interstate cereal flows for India. And more recently, Pandit et al., (2023) estimated sub-national flows between US counties and Chinese provinces using a similar approach as Karakoc et al., (2022). We contribute to this body of literature, employing a simple and easily generalizable and reproducible mass-balance approach. Beyond a few white papers (Metro Vancouver & Davies Transportation Consulting Inc., 2020; RECYC-QUÉBEC, 2022) for a couple of provinces, comprehensive provincial scale food flows for Canada, especially dissected by specific commodities, have been largely absent.

To develop provincial scale food flows for Canada, we integrate data on production, imports, and exports of fruit and vegetable commodities. The steps involved are outlined in Figure S16 and Figure S17 represents all flows of fruit and vegetable into Canadian provinces.

Step 1) Input data and harmonization

Input data

Production data

For 18 fruits and 16 vegetables, we sourced provincial production data from Statistics Canada for 2010-2022 (Statistics Canada, 2023). This data was collated from three national surveys: the Fruit and Vegetable Survey (FV), the Annual Greenhouse, Sod and Nursery Survey (GSNA), and the Biannual Potato Area and Yield Survey (PAYS). The data from these surveys are routinely used by Agriculture and Agri-Food Canada, and other federal and provincial agencies for development of national and provincial agriculture policies and programs. These surveys are conducted annually (and bi-annually in the case of PAYS) and employ stratified simple random sampling approach.

Trade data

Trade data for 18 fruits and 16 vegetables and their derived commodities was extracted using the six-digit Harmonization System (HS) code from the Canadian International Merchandise Trade Web Application provided by Statistics Canada (Statistics Canada, n.d.-b). For the list of primary and derived commodities, refer to Table S.2. This customs-based trade data encompasses provincial-level trade information with every US state and other global nations.

Specifically, the source of Canadian imports data is the Canada Border Service Agency (CBSA) B3 forms. The B3 forms detail the goods' description, value, origin, clearance port, and transport mode and are submitted when goods enter Canada. Meanwhile, export data from US states to Canada is from US Census Bureau, which uses documents from US customs and Broader Protection. Detailed insights about this data can be found at the Statistics Canada (International Merchandise Trade Statistics, n.d.) and for further clarity on HS classifications, refer to the United Nations Statistics (UNSTATS, n.d.).

In the datasets sourced from Statistics Canada, two measures of exports are available. Domestic exports represent goods originating from Canada, whether produced, cultivated, or extracted, that are subsequently exported. Re-exports are not included in this category. The dataset also includes Total Exports, which combines both domestic exports and re-exports. Re-exports pertains to goods initially imported into Canada and later exported without undergoing significant transformation within the country. Thus, while domestic exports capture Canadian-

originating goods, total exports encompass both domestically-produced and re-exported items. We use domestic exports throughout our analysis, unless explicitly mentioned.

Data harmonization

We first reconcile the production and trade data to estimate provincial-level consumption. Each dataset uses a different classification system and is available at different time-steps. The provincial-level customs-based trade data uses Harmonization System (HS) classification (UNSTATS, n.d.), a standard practice in international trade data and is available at monthly time-steps. And, the provincial-level production data uses the North American Product Classification System (NAPCS) (Statistics Canada, n.d.-c) and is available at annual time-steps and bi-annual (in case of PAYS survey).

Production data pre-processing

Three surveys provide our production data (Production), which we harmonize by prioritizing total production (actual harvested amounts) over marketed production (amount supplied for sale). For crops cultivated both in greenhouses (GSNA survey) and outdoors (FV survey), the data from these surveys are amalgamated. If data is flagged as unreliable by Statistics Canada, we resort to using the prior year's figures.

Trade data pre-processing

The six-digit HS code data covers imports and exports of 33 fruit and 22 vegetable products (Table S3), corresponding to 18 primary fruits and 16 primary vegetables in our study. For instance, fresh tomato and canned tomato products are delineated separate six-digit HS code in the trade data, while both of these correspond to the same primary vegetable, i.e., tomatoes. To do so, we first aggregated trade data from monthly to annual time steps. We then converted derived products to their primary equivalents based on calorie contents and matching keys (Kastner et al., 2014; Schwarzmüller & Kastner, 2022), ensuring alignment with domestic production figures. For example, tomato juice or canned tomatoes are converted back to fresh tomato equivalents.

After pre-processing production and trade data, we matched the production and trade classification codes to a common classification used by the United Nation's Food and

Agriculture Organization (FAO)—FAO Item Codes. We did this by using a matching key developed by FAO and based on the descriptions of each fruit and vegetable commodity in the three classification systems. Table S3 and S4 provides the matching keys used.

Data validation

To validate our harmonization efforts, we compared our national-scale aggregated data against supply-utilization accounts from the FAO. Using a simple food balance equation (consumption = production + imports – exports), we find our harmonization consistent for most commodities, with exceptions noted for potatoes, blueberries & cranberries, and chilies & peppers (Figure S18).

Step 2) Estimating provincial consumption

Despite the availability of bi-lateral trade data at provincial scale for Canada, estimating provincial scale food flows is not straightforward. The bi-lateral trade data cannot be directly used to estimate consumption and food flows for two reasons. First, the customs-based trade data is based on province of clearance (International Merchandise Trade Statistics, n.d.). Province of clearance is the province in which the food commodity enters and is cleared by customs while crossing Canadian borders, and does not necessarily mean the province of final destination for that commodity (International Merchandise Trade Statistics, n.d.). Second, the primary datasets lack information on interprovincial food flows from province of clearance to the province of consumption. We note that Canadian Freight Analysis Framework (Statistics Canada, n.d.-a) data provides some insights into interprovincial flows; however, that data is only available for aggregated commodity groups (e.g. food, fuel, agriculture inputs). In the following section, we describe how we navigated these challenges by estimating interprovincial flows and provincial-scale consumption using a mass balance approach.

In order to fill these gaps, we first estimated provincial scale consumption (Consumption) assuming annual dietary preferences are the same across provinces, in other words, we assume that provincial per-capita consumption is the same as national per-capita consumption for each commodity. Here, consumption is defined as the food available for consumption and is calculated as the sum of domestic production available for consumption (production minus

exports, *Production**) and imports. We calculated this using production and bi-lateral trade data described above. Our consumption metrics rely on available food for consumption data, not actual individual consumption figures, and does not account for food loss and waste along the supply chain.

To corroborate our assumption regarding per-capita consumption being uniform across provinces, we conducted sensitivity analysis using sales data (see Technical Validation section below). We also used household expenditure survey data for 2019 to compare expenditure on fruit and vegetable as a share of total food expenditure across the Canadian provinces (Statistics Canada, 2012). We find, on average, household expenditure on fresh fruit and vegetables as a share of total food expenditure in 2019 is comparable across provinces (Figure S19). While household expenditure is a function of various factors, such as household income, demand, supply and prices, it does provide some reference for how the dietary preferences vary across provinces. Finally, we used the Canadian Community Health Survey data (Statistics Canada, 2017) to compare how the percentage of people that consume fruits and vegetables five times or more per day vary across provinces (Figure S20). We find, in 2015 the difference between provinces ranged from 22.5% (Newfoundland and Labrador) to 32% (Alberta), except for Quebec where 39% of people consume fruits and vegetables five or more times per day.

Step 3) Identifying supply hubs and hub dependent provinces

Using our provincial consumption estimate, along with provincial production for domestic available for consumption (*Production**) and international imports (*Imports_{international}*) entering at the port of clearance, we estimated each province's supply exceeding or lagging their consumption needs. We estimated excess or deficit supply for each province, fruit and vegetable, and year as follows:

$$Supply\ excess = Production^* + Imports_{international} - Consumption$$

Provinces with excess supply are termed as "supply hubs", while those with negative supply excess are labeled "hub-dependent provinces". An illustration of this is presented in Figure S21,

showcasing British Columbia as a supply hub and Alberta as a hub-dependent province for apple supply.

Step 4) Estimating interprovincial flows

Once we identify supply hub and hub-dependent provinces for each year and fruit and vegetable, we created new interprovincial links from the *supply hubs* to the *hub-dependent* provinces, called interprovincial flows. Interprovincial flows are defined as the quantity of food transported from one province to the other. These can be either food that is produced domestically or food that is cleared by customs in supply hubs.

To deduce these flows, we adopted the inverse-distance weighting method using road distances, which distributes surplus supply from hubs to deficit provinces, factoring in their geographical proximity. Essentially, the closer two provinces are, the more substantial the flow. This method uses the shortest distance between key cities in respective provinces for weightage. For a visual representation, refer to Figure S22 that depicts the interprovincial links generated between British Columbia (*supply hub*) and Alberta (*hub-dependent* province). The equation for distributing surplus from a *supply hub* to *hub-dependent* province based on inverse-distance weighting can also be written as:

$$S_{ij} = \frac{S_i}{\sum_{j=1}^m w_{ij}} * w_{ij}$$

Where, S_{ij} represents the surplus supply allocated from *supply hub* province i to *hub-dependent* province j ; S_i is the total surplus supply available in *supply hub* i ; w_{ij} represents the weight assigned to the flow from *supply hub* i to *hub-dependent* province j based on their geographical distance. w_{ij} can also be written as: $w_{ij} = \frac{1}{d_{ij}^2}$, where d_{ij} is the geographical distance between major city in the *supply hub* province i and major city in the *hub-dependent* province j . The denominator $\sum_{j=1}^m w_{ij}$ represents the total weight associated with all deficit provinces for a particular hub province i .

Step 5) Estimating food flows

The final step concerns the reallocation of these interprovincial flows to their origin, employing a reallocation approach. Any flows to *hub-dependent* province from *supply hubs* are redistributed back to producing regions proportionately using supply shares of the *supply hub* (Figure S23). In other words, we use a probabilistic approach for this redistribution. We assume that once apples reach British Columbia, they become a homogeneous mixture. Therefore, when they are transported to Alberta, we are essentially determining the likelihood that a random apple originated from a specific supplying region.

After this redistribution process, we can distinguish the origin of food flows for each province as to whether they are produced within the province, within other provinces, or produced internationally. Post redistribution, we term flows between provinces as “rebalanced interprovincial flows”. Note that interprovincial flows and rebalanced interprovincial flows are not the same. Interprovincial flows are the flows from supply hubs to hub dependent provinces before redistributing them back to primary producing regions, whereas, rebalanced interprovincial represent the portion of interprovincial flows that are produced in supply hubs, i.e., that represent interprovincial trade. For example, if the interprovincial flow of apples to Alberta (hub-dependent province) from British Columbia’s (supply hub) is 2 million tonnes (Mt) and British Columbia’s supply share for all of its apples from California, Washington, Mexico and its own production is 0.2, 0.1, 0.3 and 0.4 respectively. Then, the 2 Mt of interprovincial flows into Alberta are attributed back to California, Washington, Mexico and British Columbia as 0.4 Mt, 0.2 Mt, 0.6 Mt and 0.8 Mt, respectively (Figure S24). The 0.8 Mt flow from British Columbia to Alberta is called interprovincial trade.

Further, we negate any possibility of double counting. Specifically, any rebalanced interprovincial flows between hubs and dependent provinces are offset against the primary flows between the original production locales and the supply hubs.

Technical validation

To deduce provincial scale flows, we operated under the presumption that dietary habits, in terms of per-capita consumption of fruits and vegetables, remain uniform across all Canadian provinces. This foundational assumption was instituted due to a lack of accessible open-source data specifying regional dietary consumption of fruits and vegetables. For validation purposes, we juxtaposed our derived food flow estimates, which assumed homogenous dietary preferences

across provinces, against estimates that take into account differential dietary preferences across these regions using some limited data that were available.

To estimate differential dietary preferences across provinces, we use Neilson IQ MarketTrack scanner data (channels: grocery banners, mass merchandisers, drugstores) on aggregated annual sale quantities for four fresh fruits and three fresh vegetables across Canadian provinces from 2019 to 2022. This data was obtained from Agriculture Agri-Food Canada through personal communication. The Neilson IQ data cover the major retail banners for grocery, mass merchandisers (excl. Costco), and drugstores, however, it does not capture all retail sales. For instance, it does not capture specialty food stores, independent stores or farmers markets.

We use per-capita volume indices for provinces (Ontario, Quebec, Alberta, British Columbia, and averaged values for Manitoba and Saskatchewan, and the Atlantic provinces) relative to national average as dietary preference indexes (Figure S23). Using these indices, we estimate provincial scale consumption and food flows that account for provincial dietary preferences.

Upon comparing the food flows based on differential dietary preference and uniform dietary preference across provinces, we find modest differences in flows. Barring a few flows across four fruit and three vegetable flows, the supply shares or absolute quantities of food flows do not substantially differ (Figure S1 for change in supply share; see Figure S2 for change in absolute quantities). For 2019 flows, we observe the large difference in flow estimates between Quebec and Manitoba for blueberries and cranberries (decrease by 70 % supply share or 8587 tonnes), Ontario and Manitoba for grapes (decrease by 28.3% or 3447 tonnes), and Ontario and Saskatchewan for chillies and peppers (decrease by 27% or 2075 tonnes). For the rest of the fruit and vegetable flows, the difference between flows ranges from 17% increase in supply share (1703 tonnes) for Ontario to Saskatchewan carrots and turnip flows, to 15% decrease in supply share (1700 tonnes) for Prince Edward Island to Saskatchewan blueberries and cranberries flow. Comparisons for other years (2020 to 2022) can be found in the Appendix (Figures S3:S8).

Text S2. Comparison of Weather Extreme Exposure with the IPCC CMIP6 Climate Atlas

Systematic validation of weather extreme exposure is challenging due to methodological differences across studies. Nevertheless, the spatial patterns we observe over croplands are broadly consistent with exposure estimates derived from climate simulations at coarser spatial scales. We compared our results with the IPCC Climate Atlas (<https://interactive-atlas.ipcc.ch/>) while noting key differences: our estimates focus on cropland during the growing season using SSP2-4.5 across nine CMIP6 models (to control for hot-mode issues), whereas the Climate Atlas provides annual exposure over the entire globe using all available CMIP6 models under the same scenario.

Visual comparisons show broadly similar spatial patterns (Figure S24: S27). For example, exposure to days above 35°C in Brazil, the Pacific Southwest, and Mexico aligns closely with our estimates. Frost day exposure from the Climate Atlas also matches our results, confirming declining frost days in western and eastern North America, Northern Europe, the Tibetan Plateau, East-Central Asia, and western South America. Precipitation-based extremes are more uncertain due to high variability across models. Nonetheless, we observe consistent mixed signals for changes in consecutive dry days, including drying trends in western North America, Brazil, southern Africa, and parts of western Europe.

To our knowledge, no existing studies assess exposure to weather extremes for fruit and vegetable supply chains at the provincial level in Canada, precluding direct validation at this scale. Nevertheless, these comparisons indicate that our results are broadly consistent with previous work, lending confidence in the relative magnitude and spatial distribution of our estimates.

Difference in supply share from source to destination for 2019

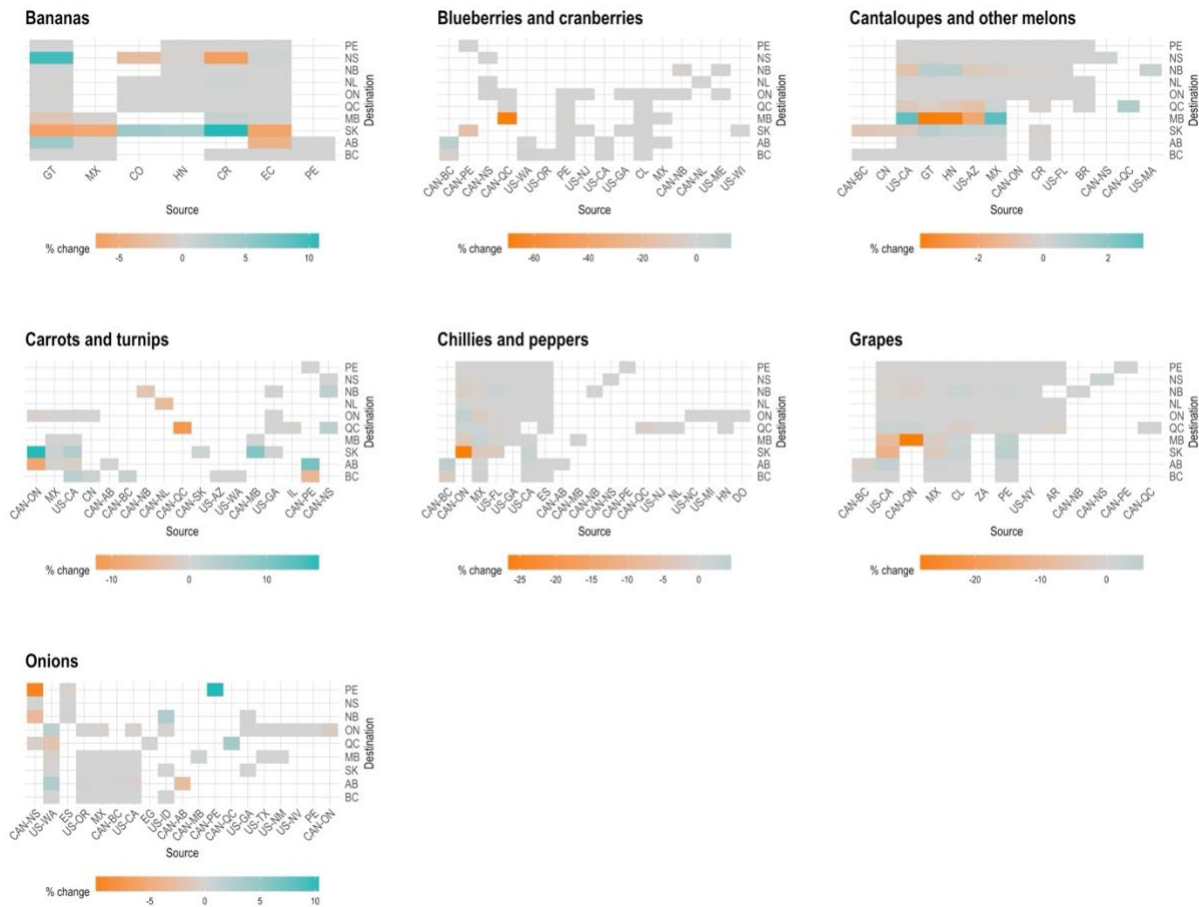


Figure S 1. Sensitivity of food flows to provincial preferences for fruits and vegetables. We compare the supply shares estimates, calculated as flow quantities from source to destination compared to total supply to destination, that account for differential dietary preference and homogenous dietary preference across Canadian provinces. The figure shows change in supply share (percentage) for four fruits and three vegetables for the year 2019.

Difference in flow estimates for 2019

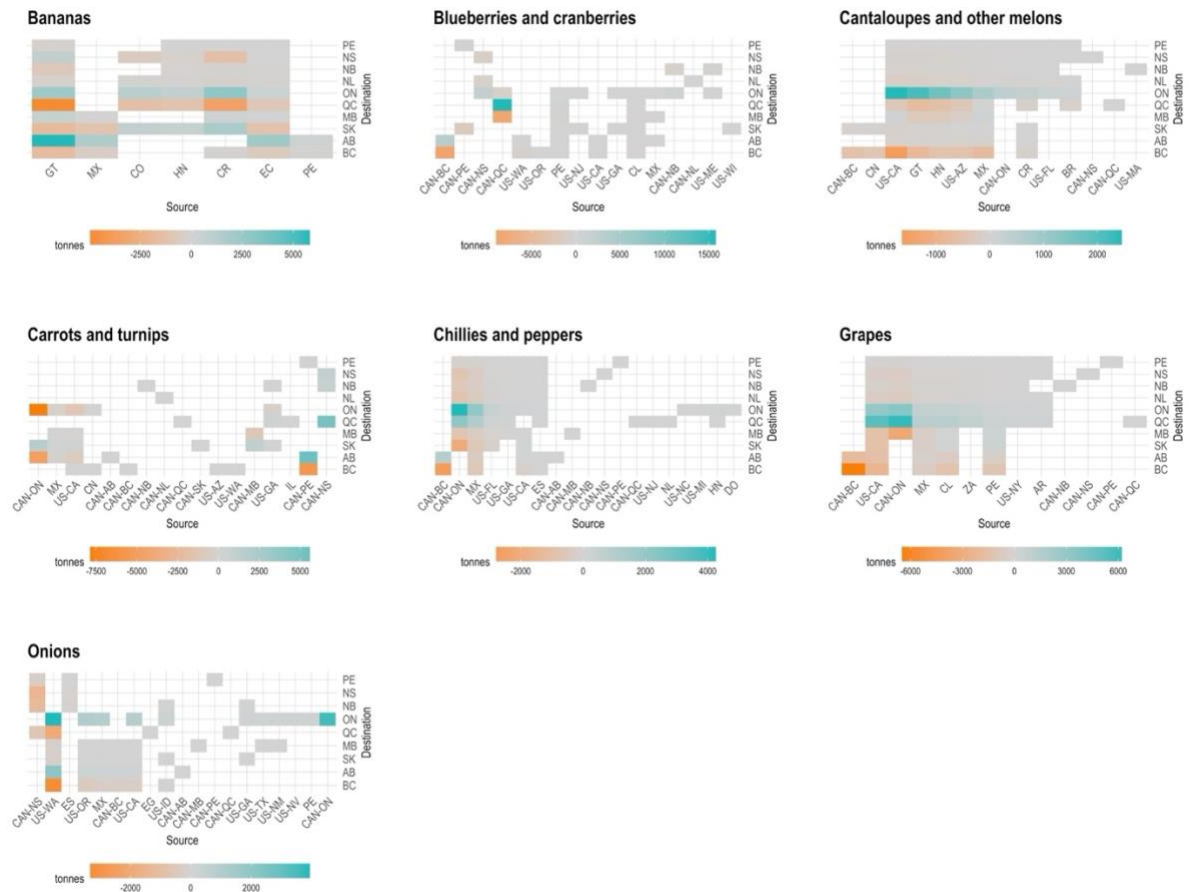


Figure S 2. Sensitivity of fruit and vegetable flows to provincial preferences based on flow estimates for the year 2019. We compare the change in flow quantities (in tonnes), calculated as flow quantities from source to destination compared to total supply to destination, that account for differential dietary preference and homogenous dietary preference across Canadian provinces (BC: British Columbia, AB: Alberta, SK: Saskatchewan, MB: Manitoba, QC: Quebec, ON: Ontario, NL: Newfoundland and Labrador, NB: New Brunswick, NS: Nova Scotia, PE: Prince Edward Island).

Difference in flow estimates for 2020

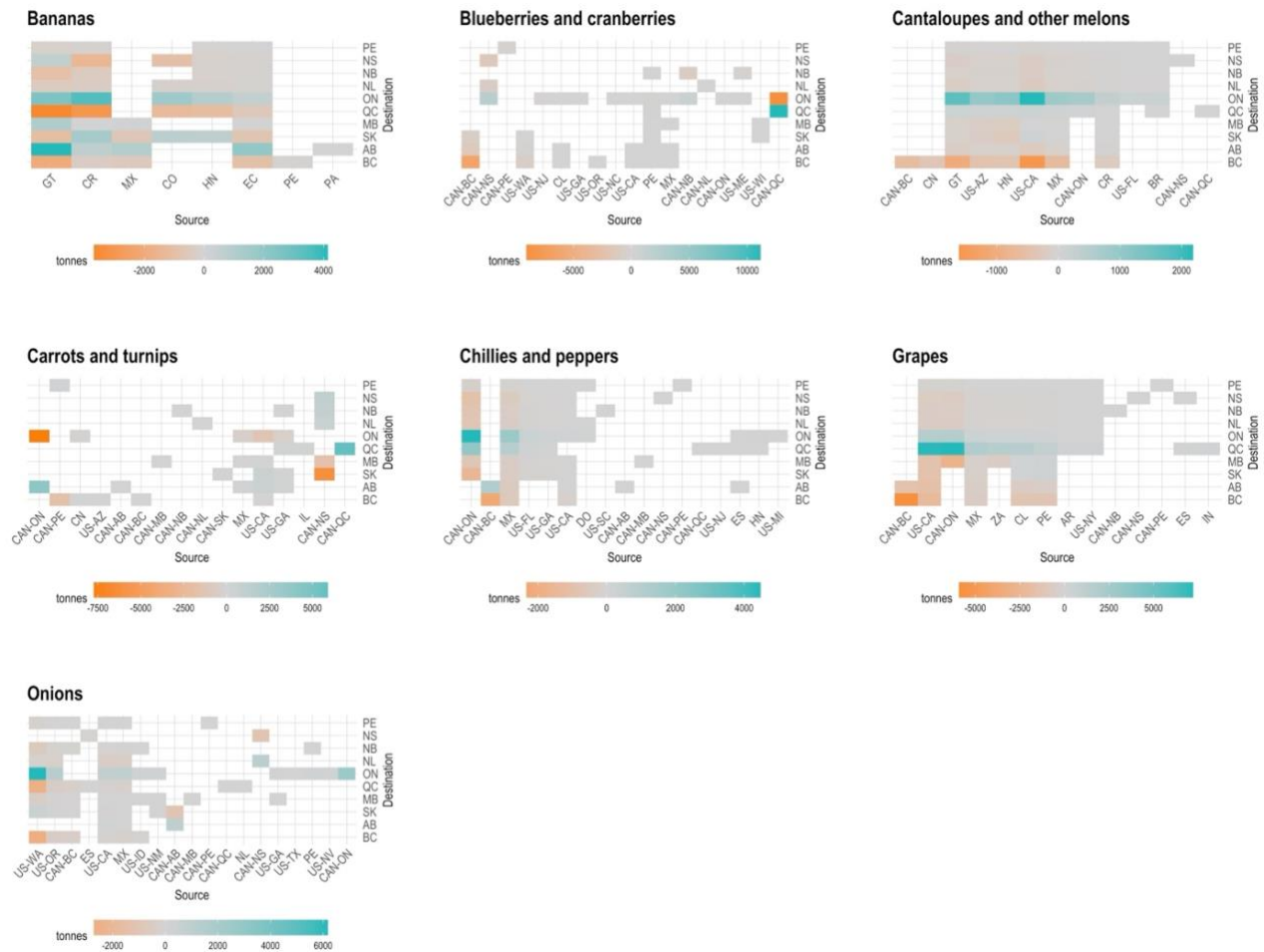
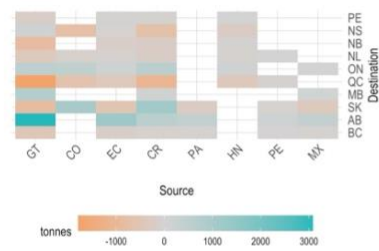


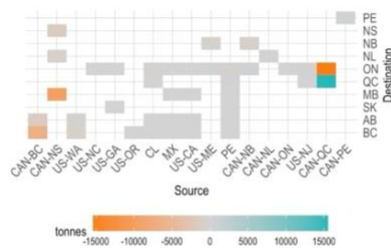
Figure S 3. Sensitivity of fruit and vegetable flows to provincial preferences based on flow estimates for the year 2020.

Difference in flow estimates for 2021

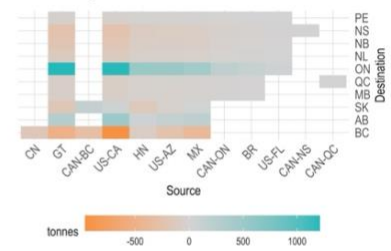
Bananas



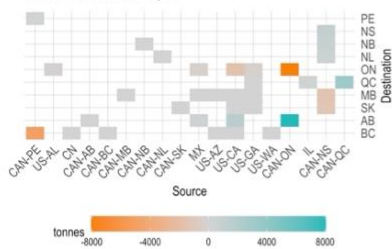
Blueberries and cranberries



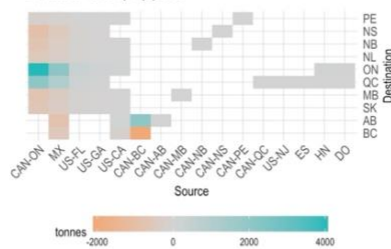
Cantaloupes and other melons



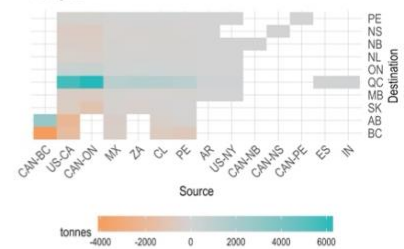
Carrots and turnips



Chillies and peppers



Grapes



Onions

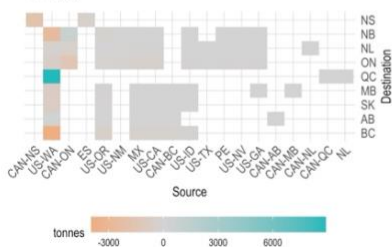
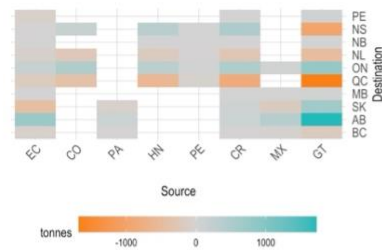


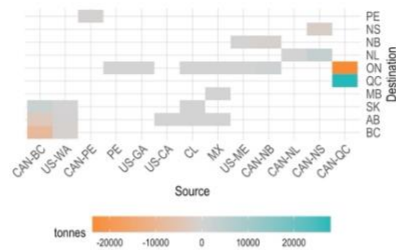
Figure S 4. Sensitivity of fruit and vegetable flows to provincial preferences based on flow estimates for the year 2021.

Difference in flow estimates for 2022

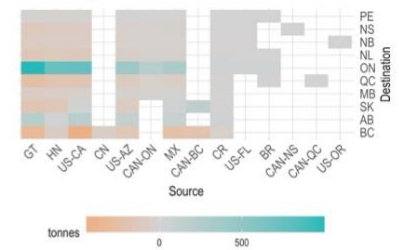
Bananas



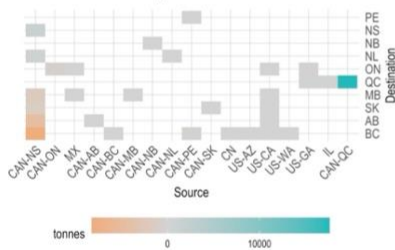
Blueberries and cranberries



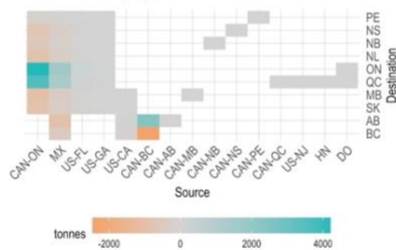
Cantaloupes and other melons



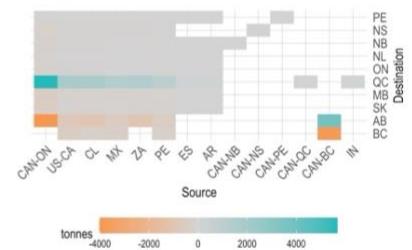
Carrots and turnips



Chillies and peppers



Grapes



Onions

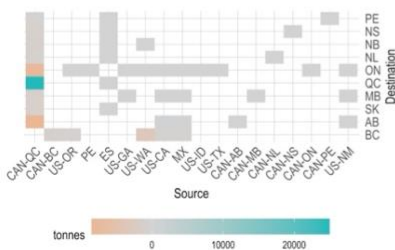
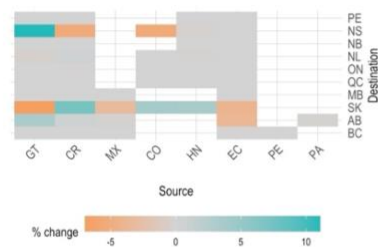


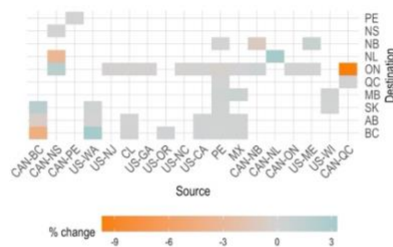
Figure S 5. Sensitivity of fruit and vegetable flows to provincial preferences based on flow estimates for the year 2022.

Difference in supply share from source to destination for 2020

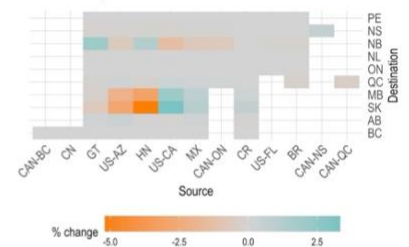
Bananas



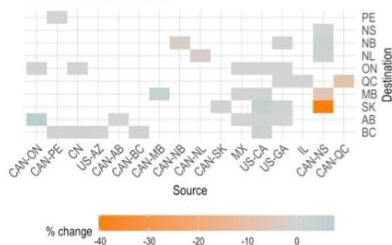
Blueberries and cranberries



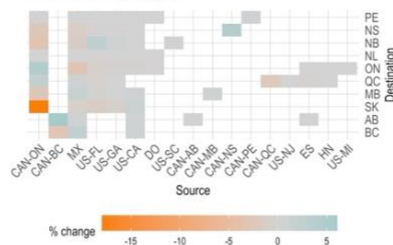
Cantaloupes and other melons



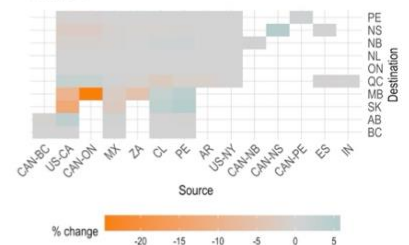
Carrots and turnips



Chillies and peppers



Grapes



Onions

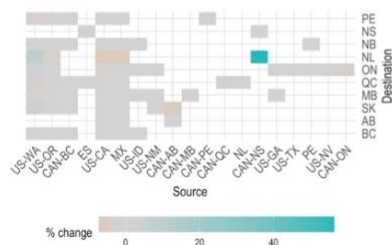


Figure S 6. Sensitivity of fruit and vegetable flows to provincial preferences based on supply shares for the year 2020.

Difference in supply share from source to destination for 2021

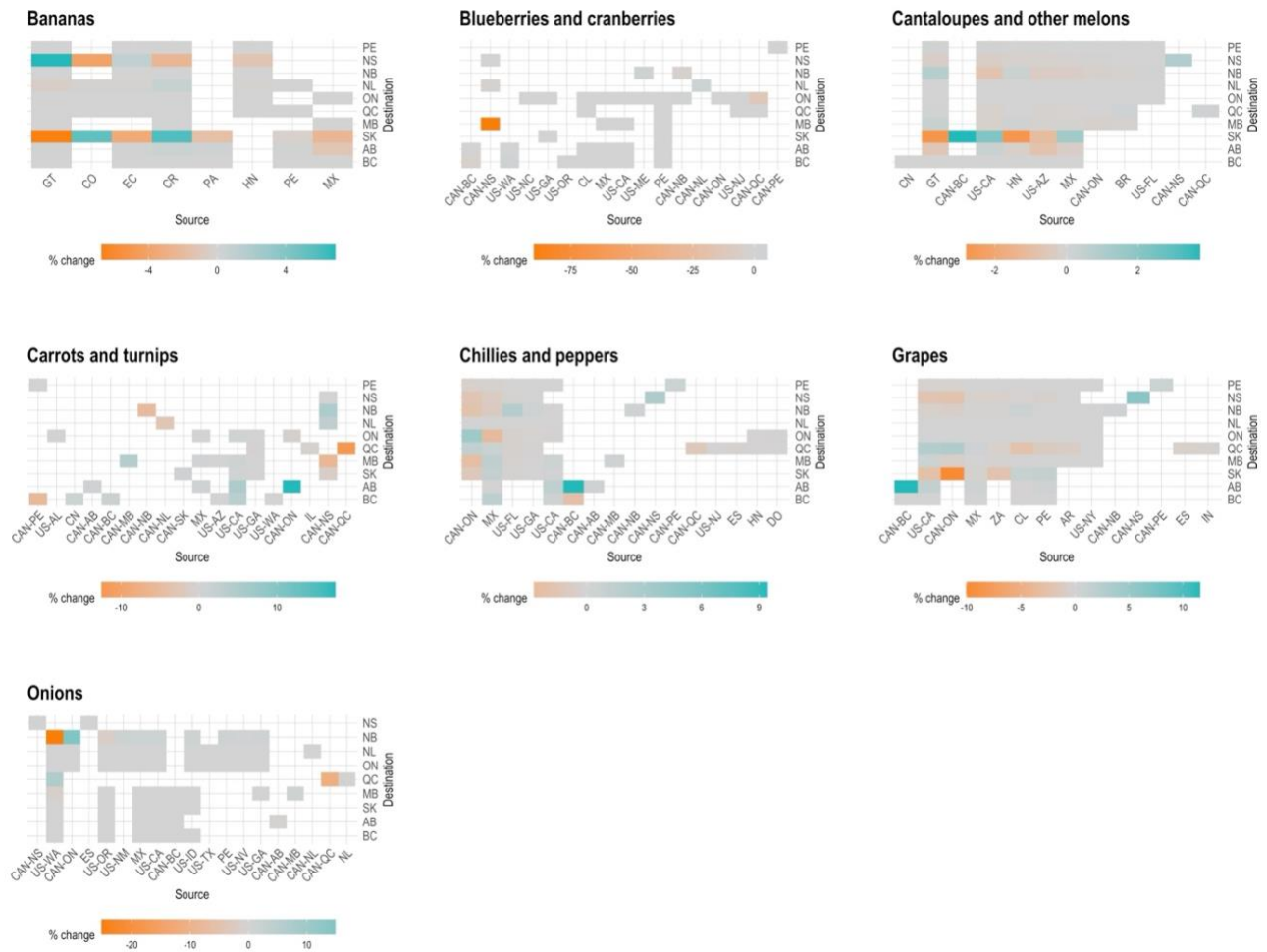


Figure S 7. Sensitivity of fruit and vegetable flows to provincial preferences based on supply shares for the year 2021.

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327
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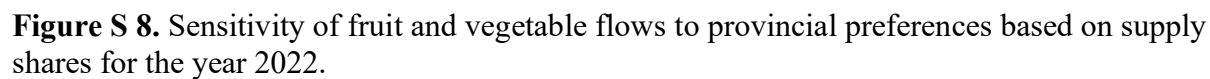




Figure S 9. Fruit and vegetable supply to Canadian provinces. The figure represents the distribution of consumption sources among international, interprovincial, and domestic regions across Canadian provinces for 18 fruits and 16 vegetables included in our analysis. Each distinct panel corresponds to a specific fruit or vegetable category, as indicated by the accompanying label. Within each panel, individual bars are allocated to the various Canadian provinces, denoted along the x-axis (BC: British Columbia, AB: Alberta, SK: Saskatchewan, MB: Manitoba, QC: Quebec, ON: Ontario, NL: Newfoundland and Labrador, NB: New Brunswick, NS: Nova Scotia, PE: Prince Edward Island).. These bars are further segmented to showcase the percentage of supply, represented on the y-axis, attributed to international sources (depicted in green), interprovincial sources (depicted in orange), or domestic sources (depicted in yellow). The numerical value within each segmented area denotes the corresponding supply proportion. Additionally, the numerical value positioned atop each bar signifies the average consumption quantity of the respective fruit or vegetable for each province, averaged across the years 2018 to 2022.

International Interprovincial Domestic



Figure S 10. Fruit and vegetable supply to Canadian provinces by sourcing regions. The figure represents the distribution of consumption sources among international, interprovincial, and domestic regions across Canadian provinces for 18 fruits and 16 vegetables included in our analysis. Each distinct panel corresponds to a specific fruit or vegetable category, as indicated by the accompanying label. Within each panel, individual bars are allocated to the various Canadian provinces, denoted along the x-axis (BC: British Columbia, AB: Alberta, SK: Saskatchewan, MB: Manitoba, QC: Quebec, ON: Ontario, NL: Newfoundland and Labrador, NB: New Brunswick, NS: Nova Scotia, PE: Prince Edward Island). These bars are further segmented to showcase the percentage of supply, represented on the y-axis, attributed to producing regions across international sources (depicted in green), interprovincial sources (depicted in orange), or domestic sources (depicted in yellow). The labels in each segmented area denotes the producing region that the province sources from. Additionally, the numerical value positioned atop each bar signifies the average consumption quantity of the respective fruit or vegetable for each province, averaged across the years 2018 to 2022.

Fruits

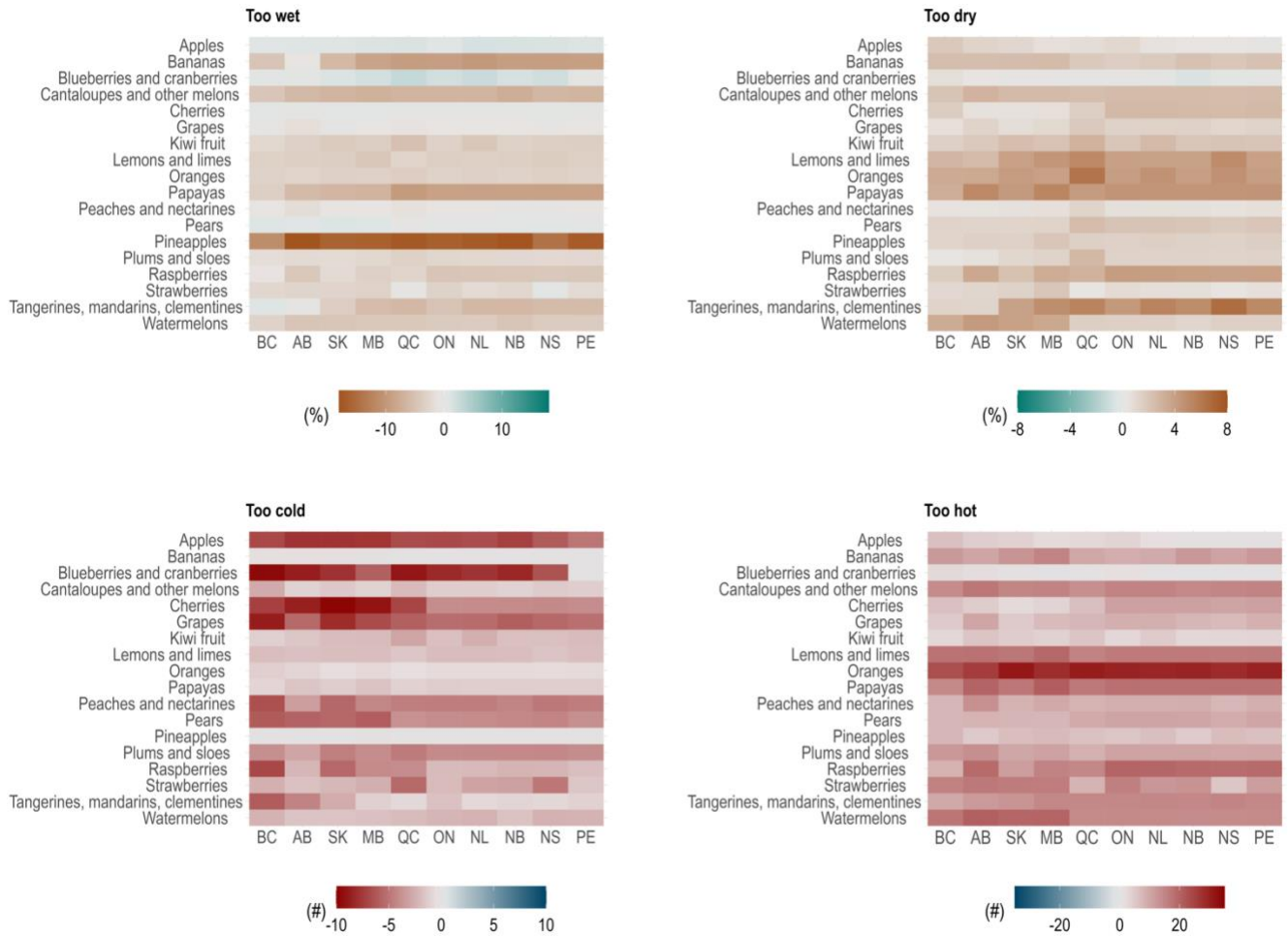


Figure S 11. Consumption-based extreme weather exposure of Canadian provincial fruit supply. The figure shows the consumption-based exposure of the most commonly consumed fruits and vegetables supply to projected weather extremes in a 2°C warmer climate than today. The panels correspond to the four key weather extreme indicators analyzed in our study: excessive rain, dry spells, cold snaps, and heat stress. Each heatmap delineates Canadian provinces on the x-axis (BC: British Columbia, AB: Alberta, SK: Saskatchewan, MB: Manitoba, QC: Quebec, ON: Ontario, NL: Newfoundland and Labrador, NB: New Brunswick, NS: Nova Scotia, PE: Prince Edward Island) and the most consumed fruits and vegetables on the y-axis. The values within the heatmaps indicate consumption-based exposure, which reflects the combined extreme weather exposure across all sourcing regions (both domestic and international), weighted according to their supply contributions.

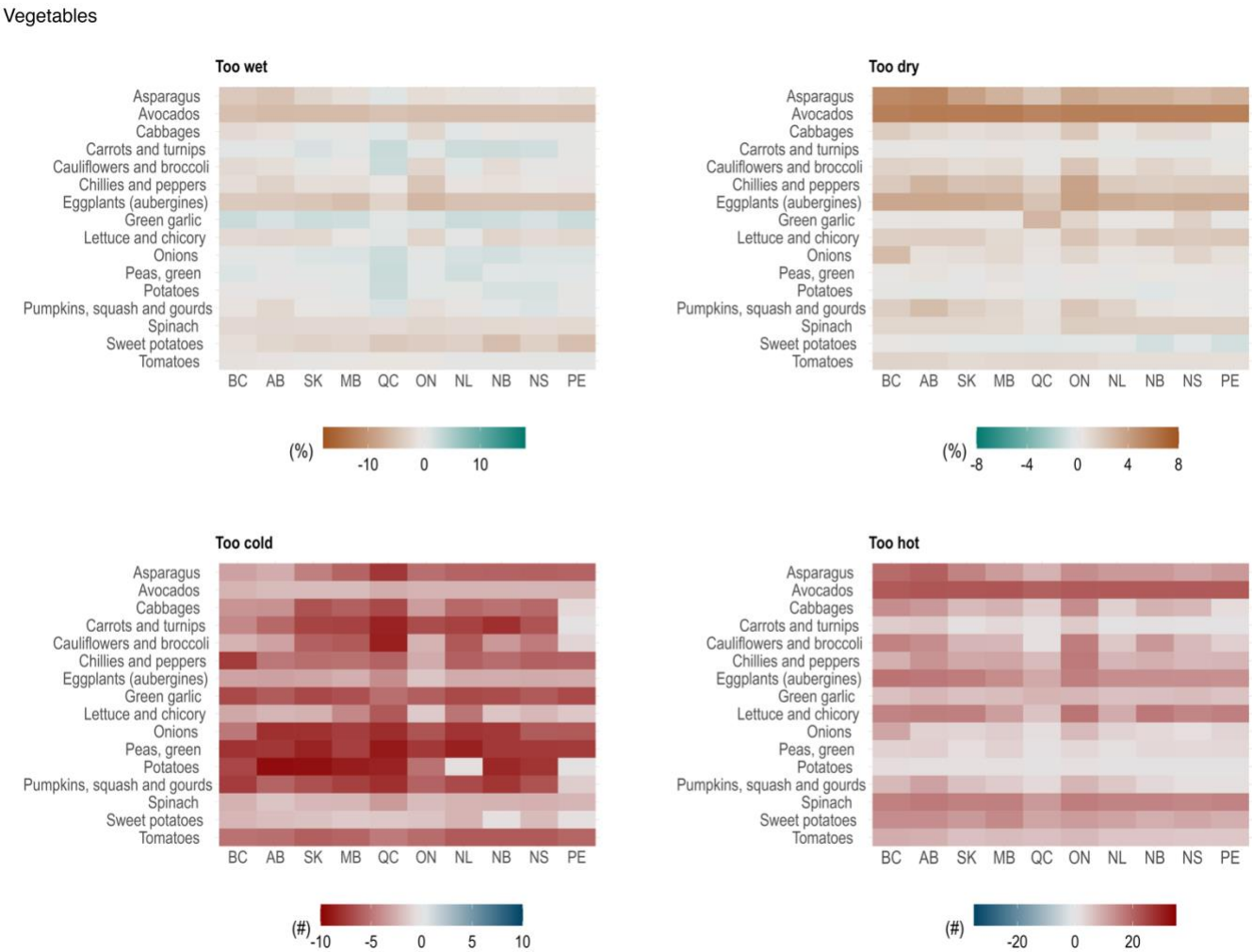


Figure S 12. Consumption-based extreme weather exposure of Canadian provincial vegetables.

Fruits

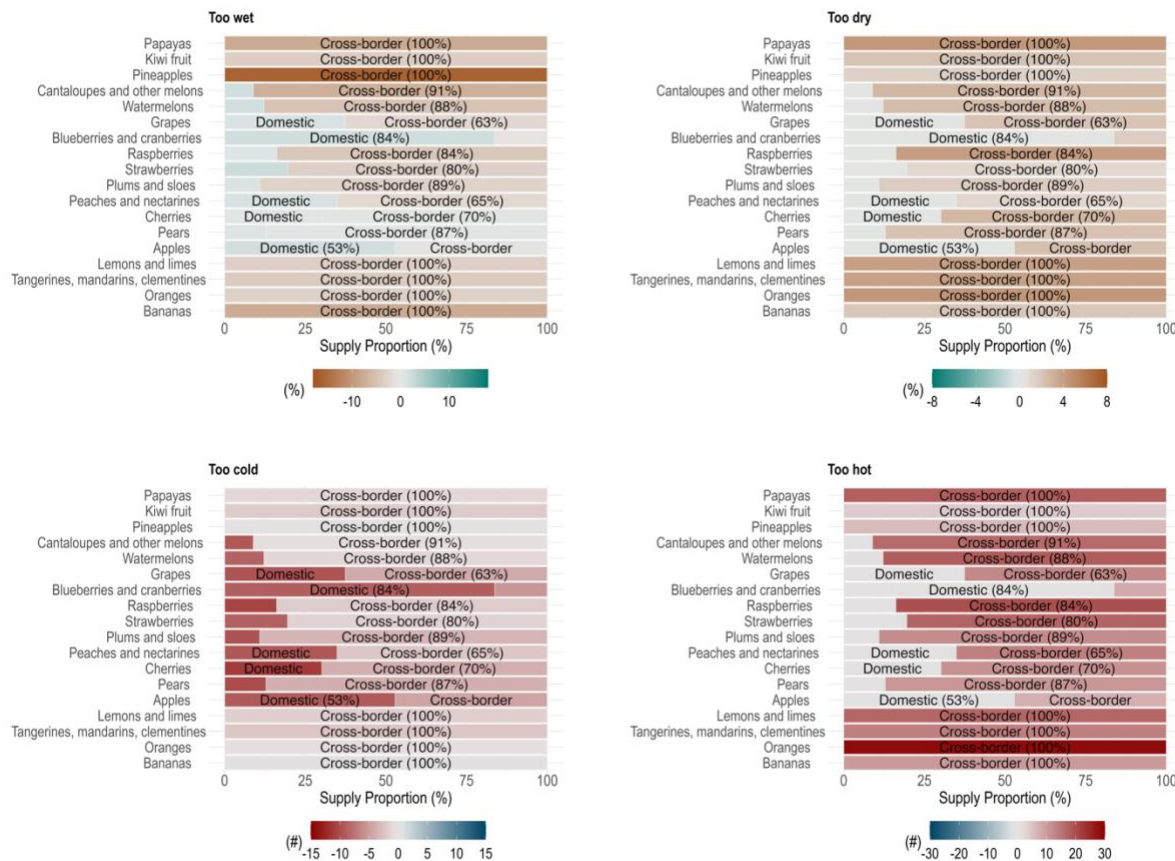


Figure S 13. Cross-border extreme weather exposure of Canada’s fruit supply. This figure delineates the domestic versus cross-border exposure to extreme weather events for Canada's most consumed fruits and vegetables in a 2°C warmer climate to today. The panels correspond to the four principal weather extreme indicators studied: excessive rain, dry spells, cold snaps, and heat stress. Within each panel, bars represent fruits and vegetables (y-axis labels), with stacks within each bar representing supply share from domestic versus cross-border regions (x-axis labels). Stack colors demonstrate domestic and cross-border exposure. Certain labels are omitted for clarity. Here, cross-border exposure entails aggregated extreme weather exposure across all international sourcing regions, weighed by their contribution to Canada's total imports. Conversely, domestic exposure stems from extreme weather exposure across all sourcing regions within Canada, weighed by their contribution to total domestic supply. In instances where a fruit or vegetable is not domestically produced, exposure is assumed as zero.

Vegetables

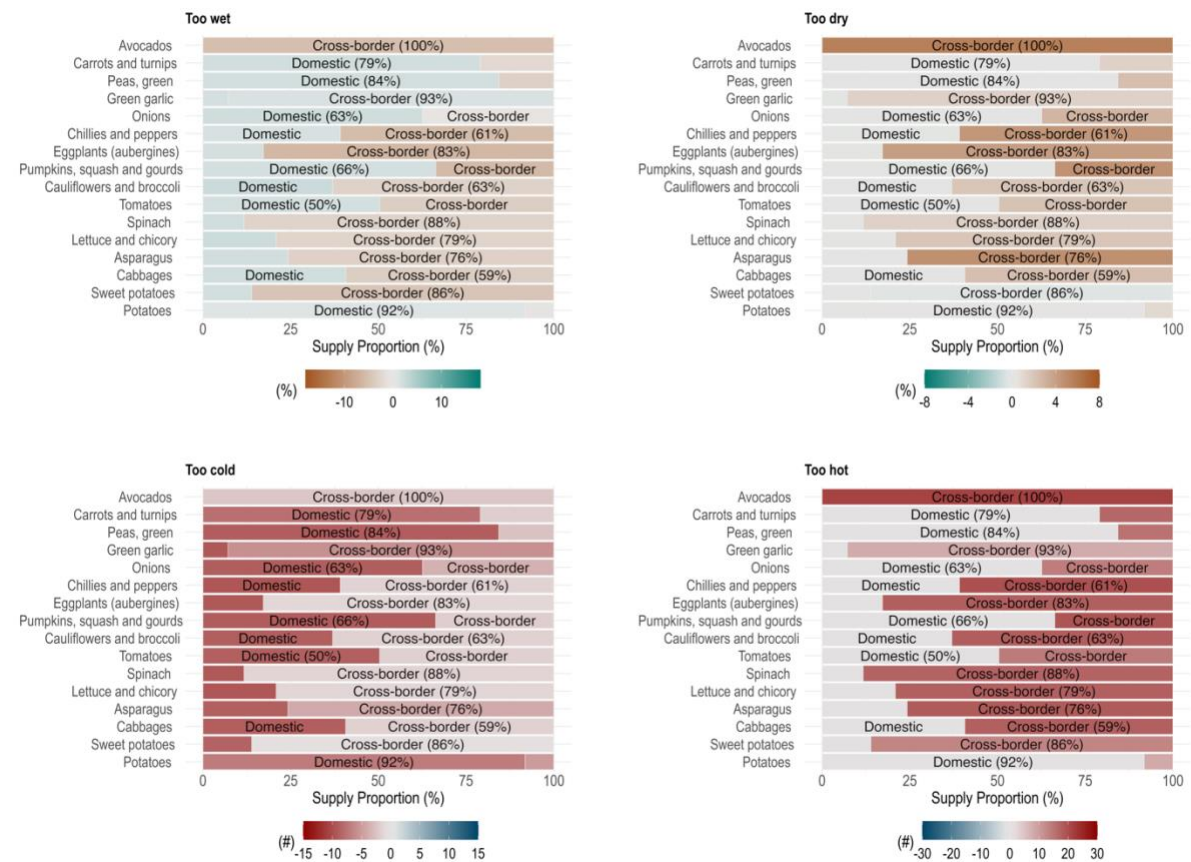


Figure S 14. Cross-border extreme weather exposure of Canada's vegetable supply.

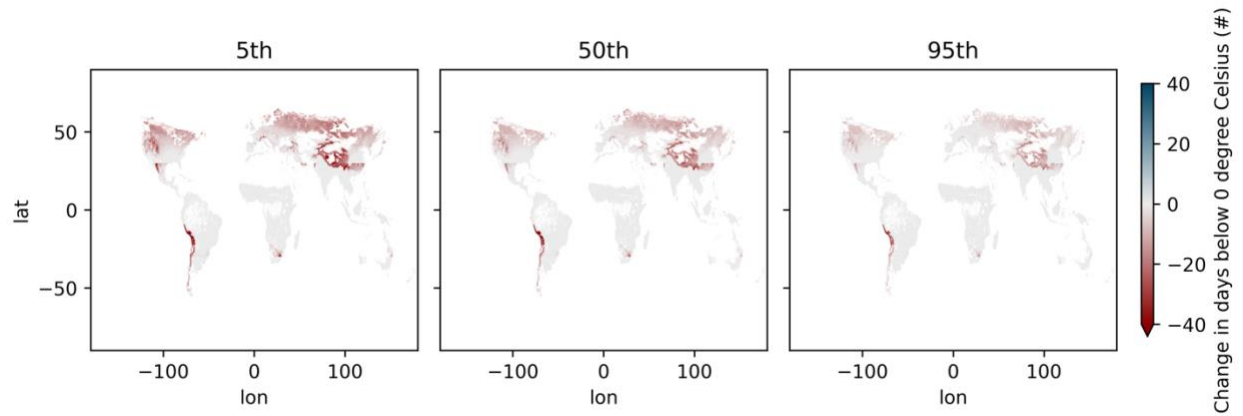
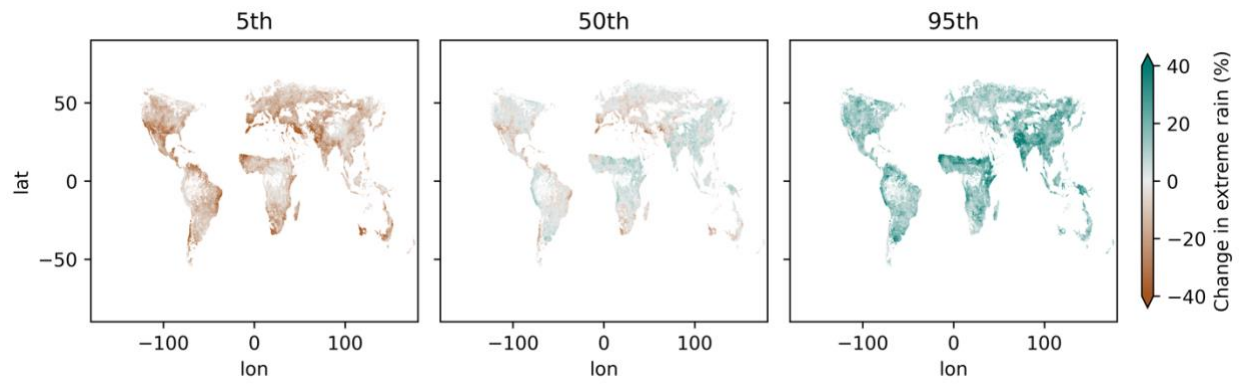
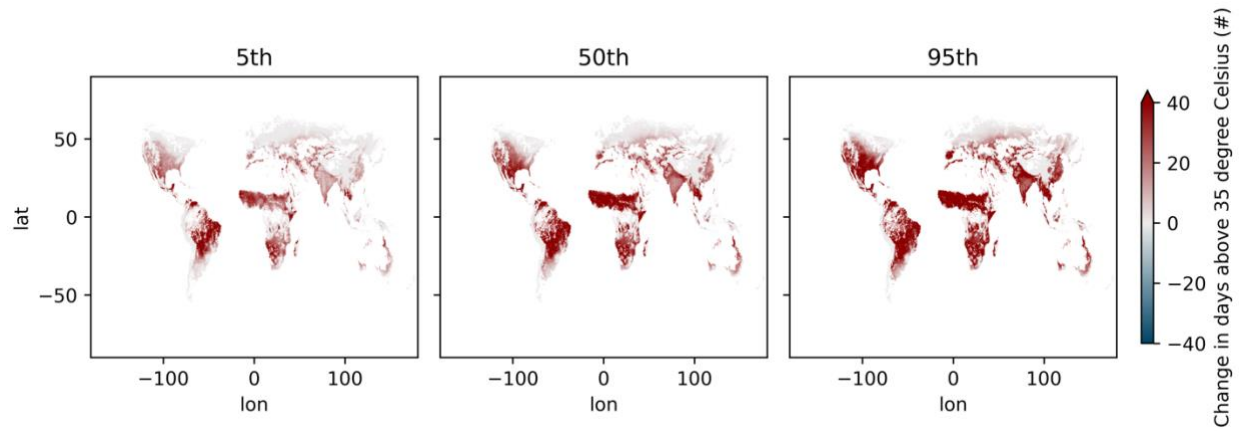
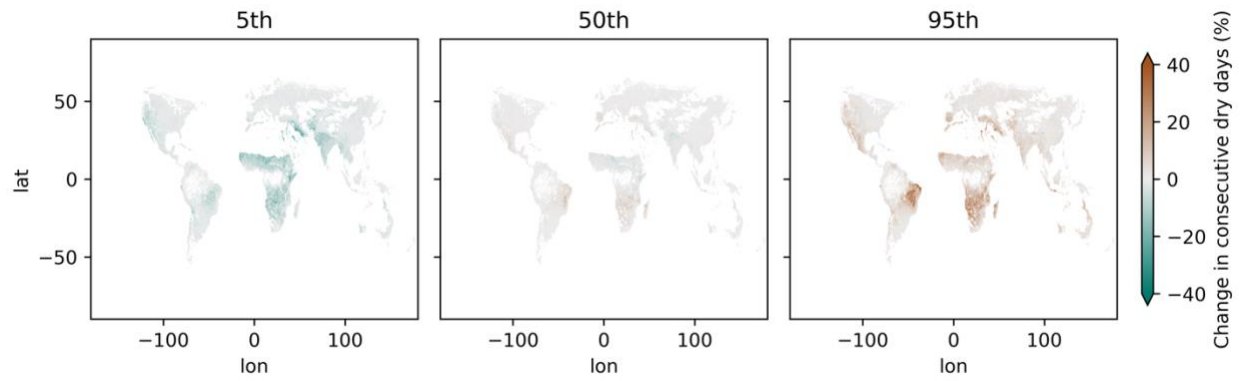
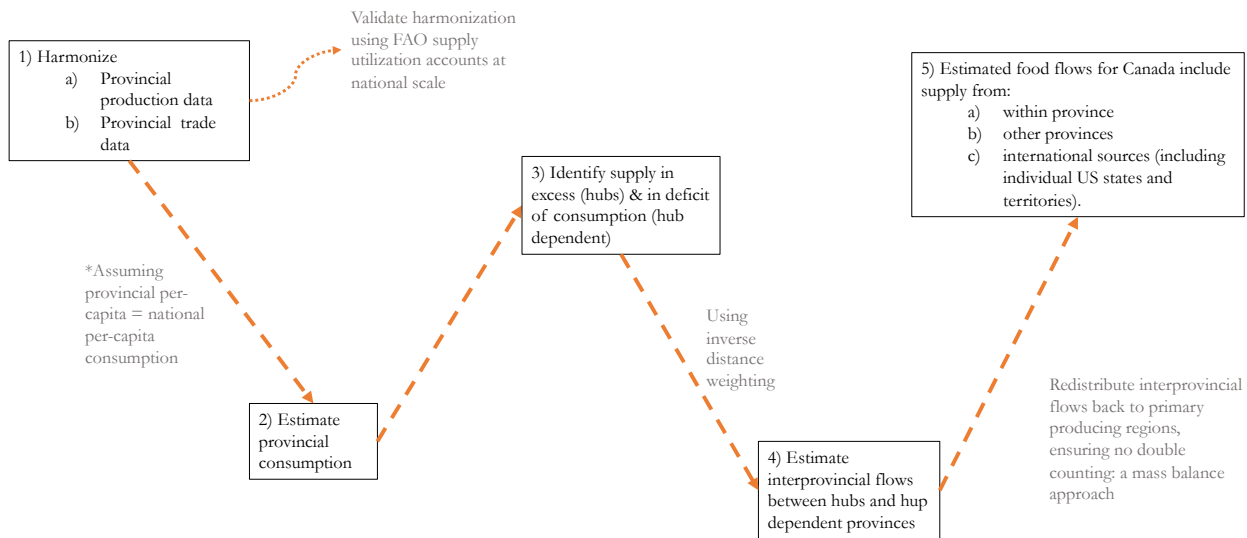


Figure S 15. Ensemble estimates of extreme weather indices. The panel presents the 5th, 50th and 95th percentile estimates (columns) of four extreme weather indices (rows) derived from nine climate models.



* Sensitivity analysis conducted using Neilson's sales data to account for regional preferences

Figure S 16. Methodological approach used to estimate provincial scale food flow to Canadian provinces. This flow diagram shows the major steps taken and the assumptions made to estimate Canada's fruit and vegetable flows. We 1) harmonized the input data, 2) estimated provincial consumption estimates over time, 3) identified the annual supply in excess or in deficit of consumption for each province and fruit or vegetable, 4) developed interprovincial flows between supply hubs and hub dependent provinces, and 5) lastly redistributed interprovincial flows back to primary producing regions to estimate food flows. In the figure, FAO represents data from Food and Agriculture Organisation of the United Nations.

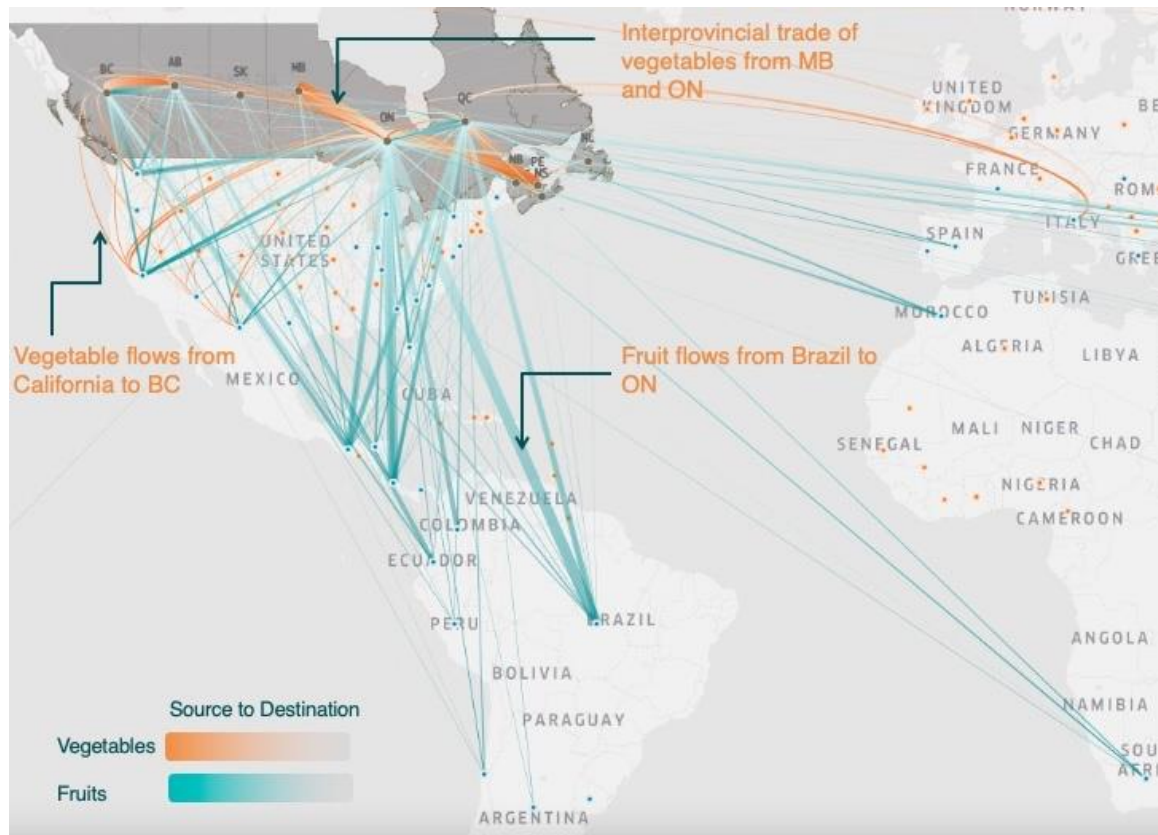


Figure S 17. Major fruit and vegetable flows to Canadian provinces. The map shows major fruit and vegetable flows to Canadian provinces for the year 2020. The links (darker color to lighter color) represent flows from source to destination regions. The color of the links represents fruits (blue) and vegetables (orange). Only the major links (based on linear scaling of flow quantities) are presented in the map. The blue (fruit) and orange (vegetable) circles represent all sourcing regions irrespective of flow quantities. The grey color represents Canadian provinces. The thickness of the links is proportional to the flow quantities.

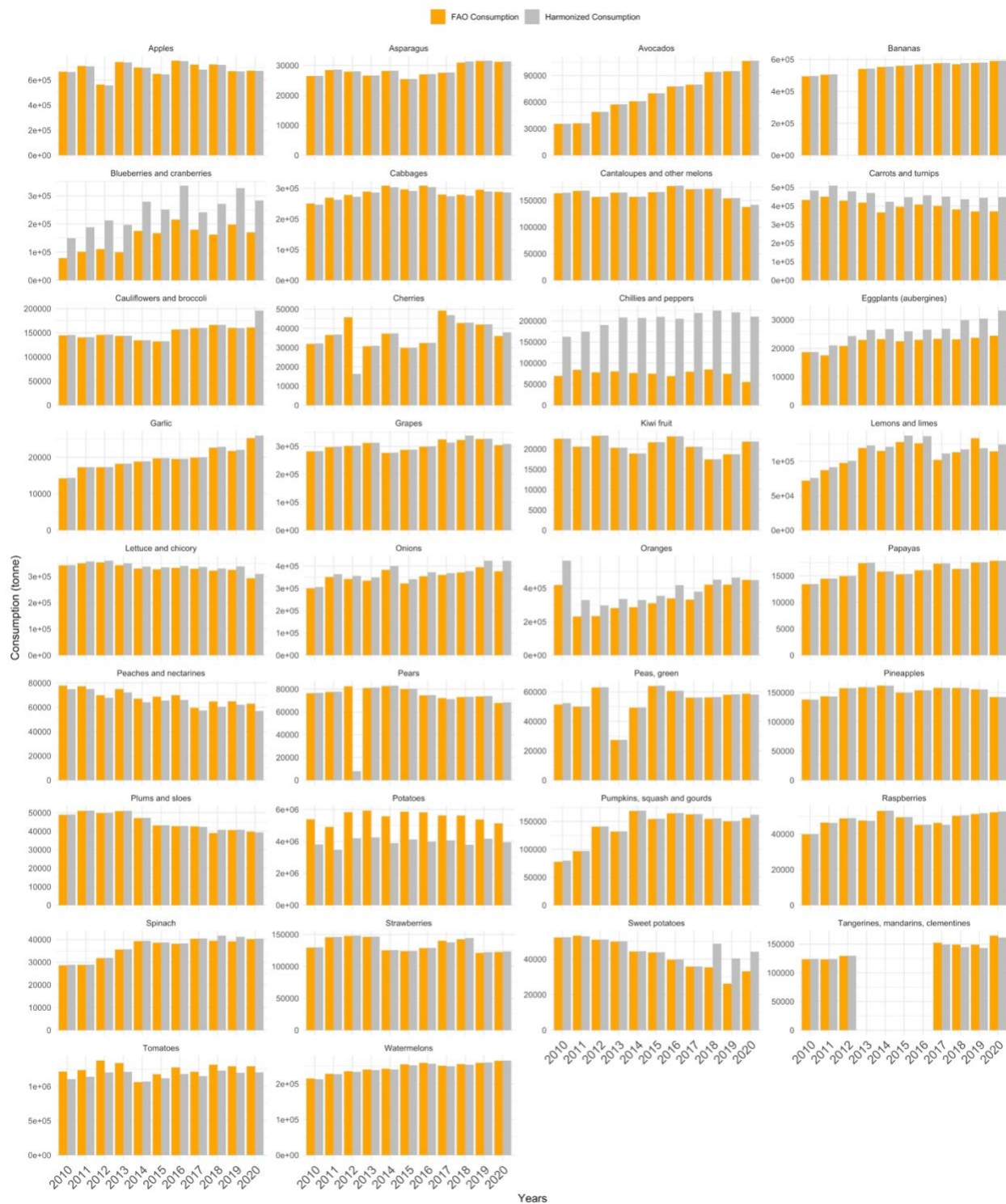


Figure S 18. Validation of data harmonization. The figure compares the consumption estimates based on FAO supply-utilization accounts and our national aggregate consumption estimates using provincial scale data on production and HS06 trade data.

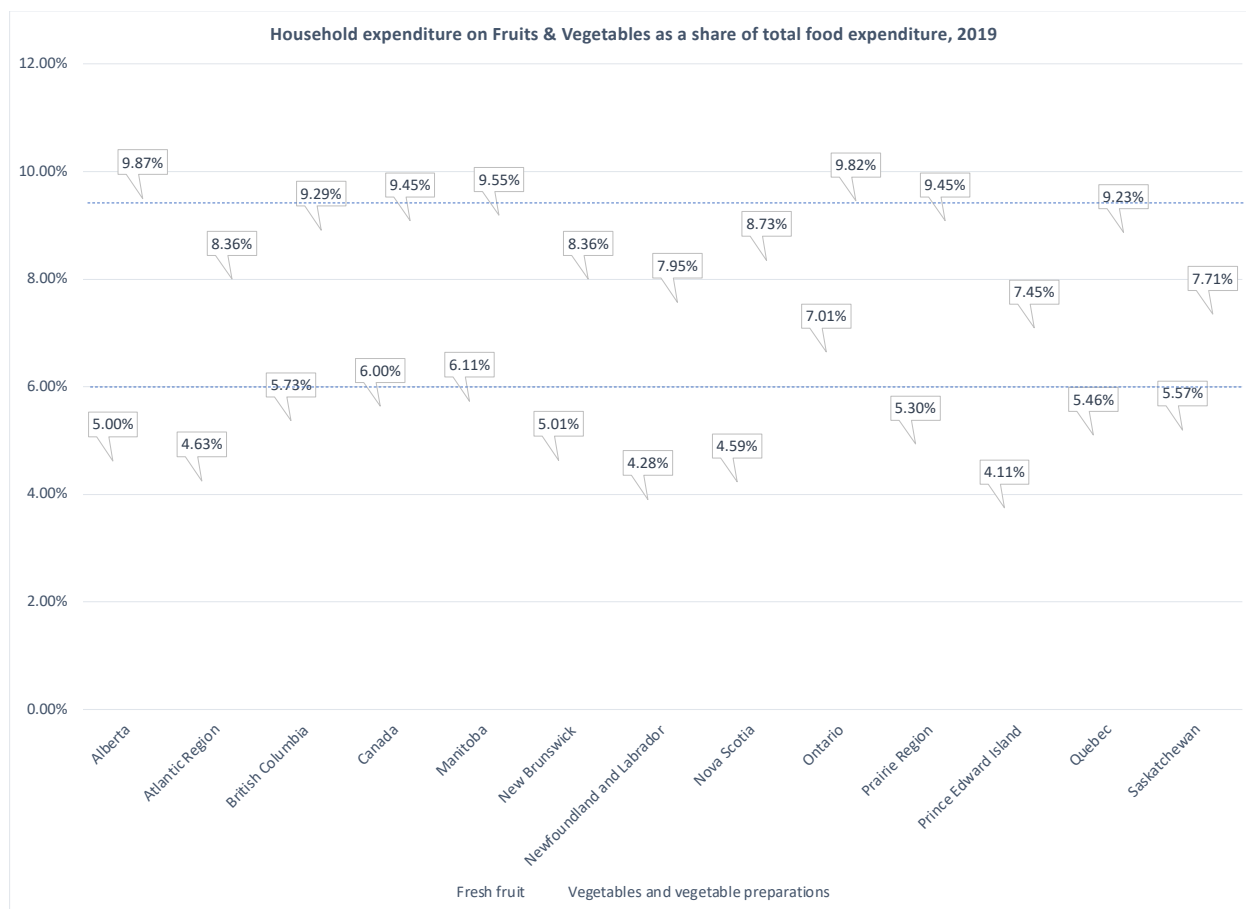


Figure S 19. Canada's household expenditure on fruits and vegetables in 2019. The bars show the share of householder spending on fruits (in green) and vegetables (in blue) compared to total food expenditure across the Canadian provinces. The dotted line represents average national household expenditure on fruits and vegetable expenditure as a share of total household food expenditure.

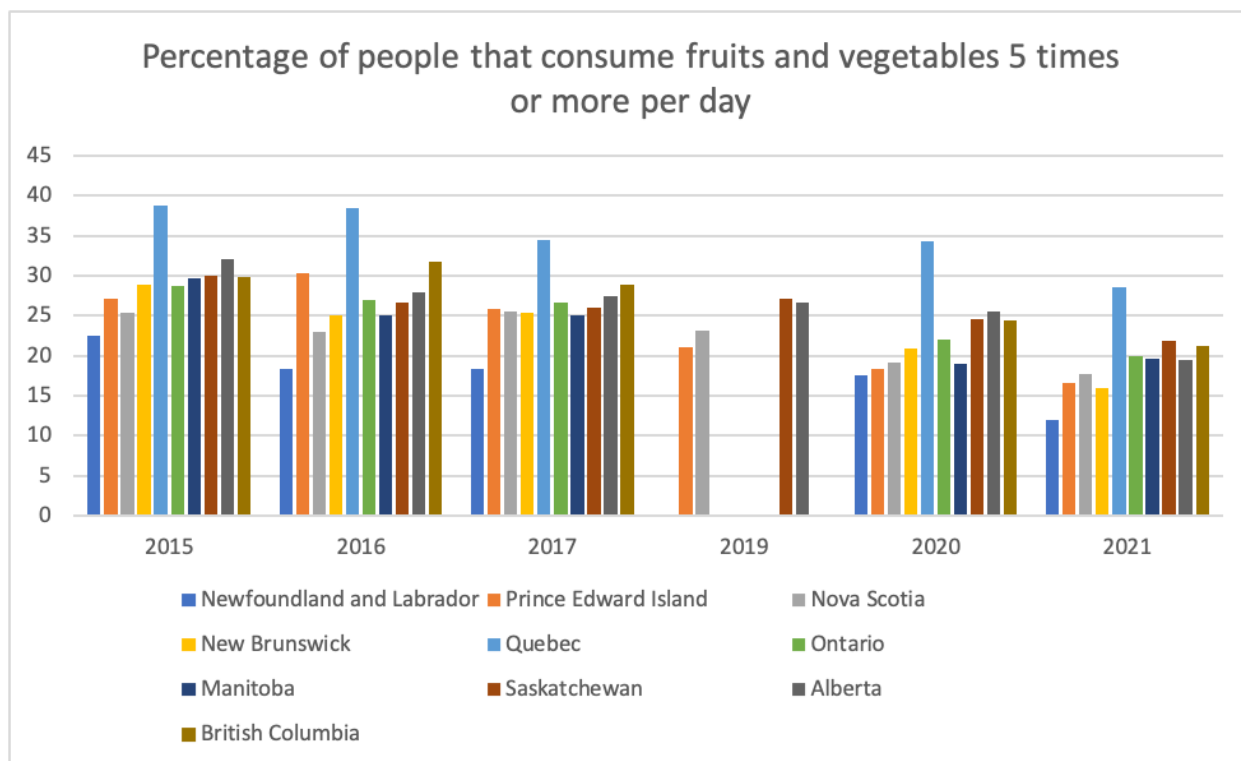


Figure S 20. Fruit and vegetable consumption in Canada. The percentage of people that consume fruits and vegetables five times or more per day by Canadian provinces and year based on Community Health Survey data

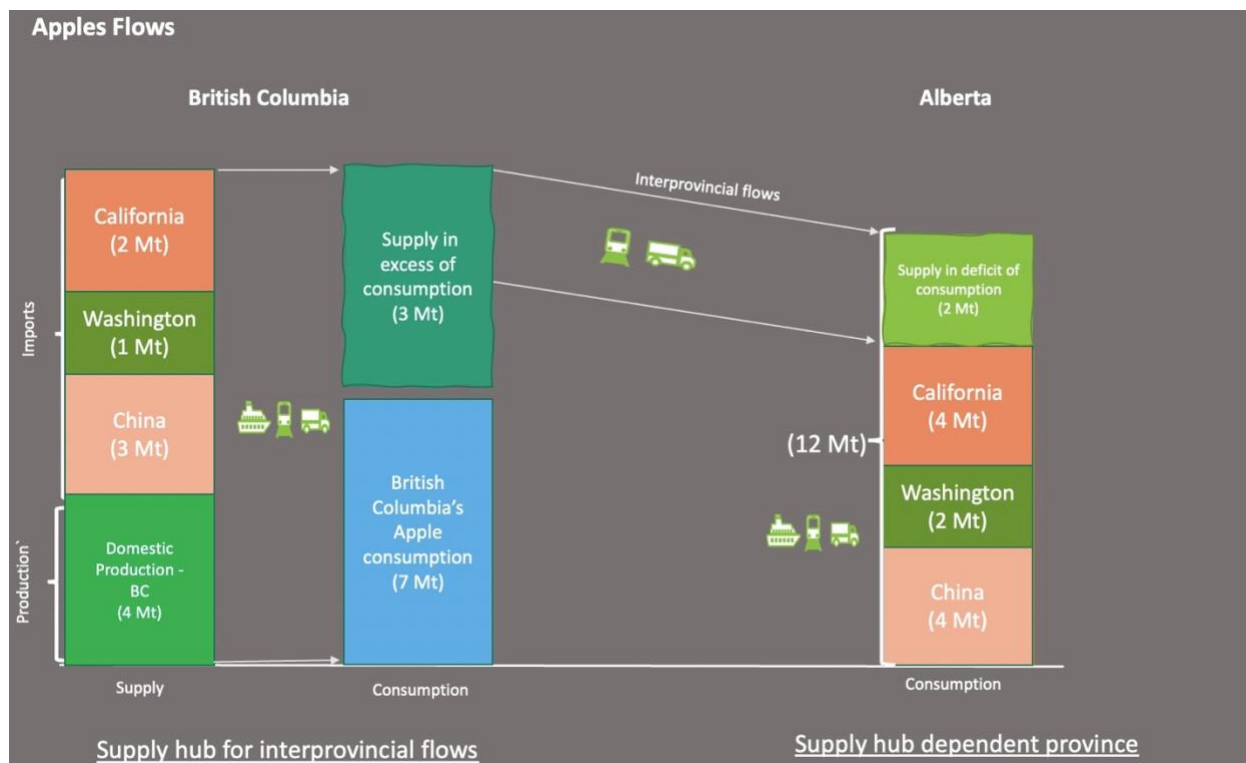


Figure S 21. Graphical illustration of supply hubs and hub dependent provinces. In this figure, British Columbia acts as a supply hub as its supply from its own provincial production and international imports is in excess of its consumption. And, Alberta as a hub-dependent province because its supply from within province production and international imports is in deficit of its consumption. The interprovincial flows from British Columbia to Alberta represent the part of excess supply from British Columbia that is distributed to Alberta to meet its consumption needs.

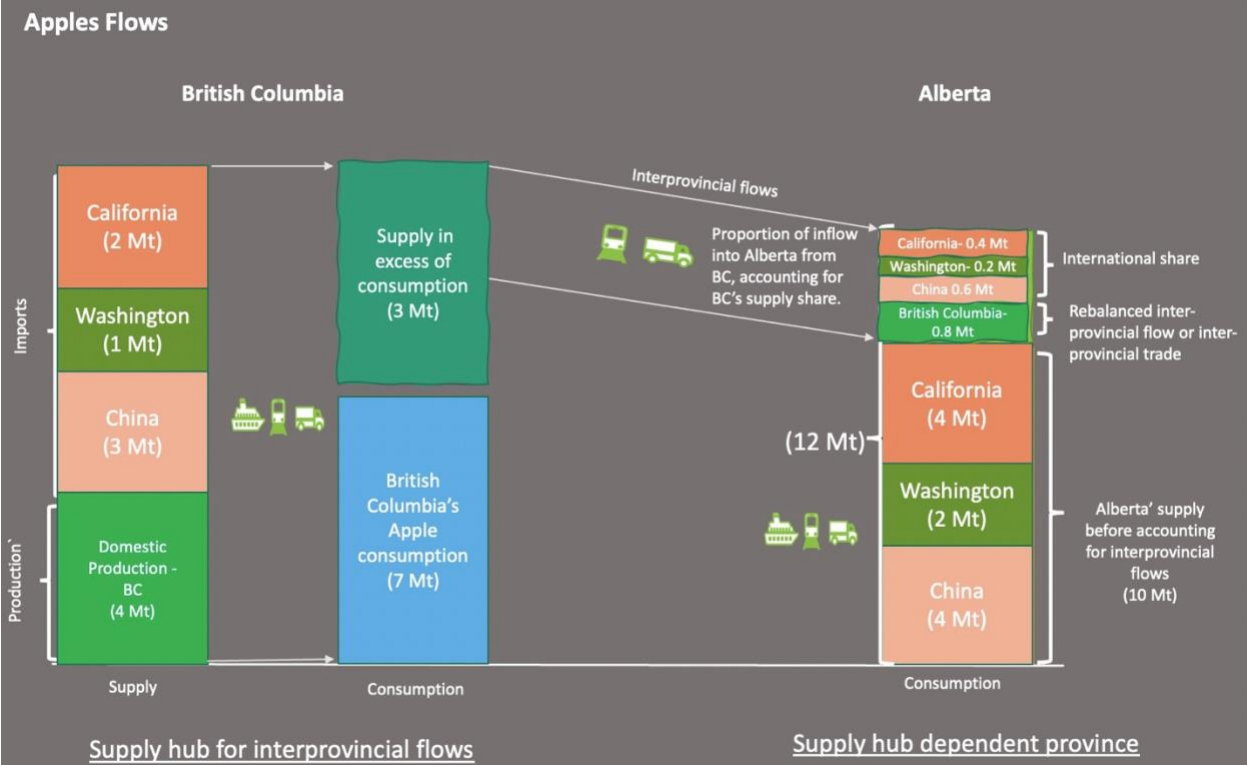


Figure S 22. Graphical illustration of how interprovincial flows are traced back to the producing regions in the analysis.

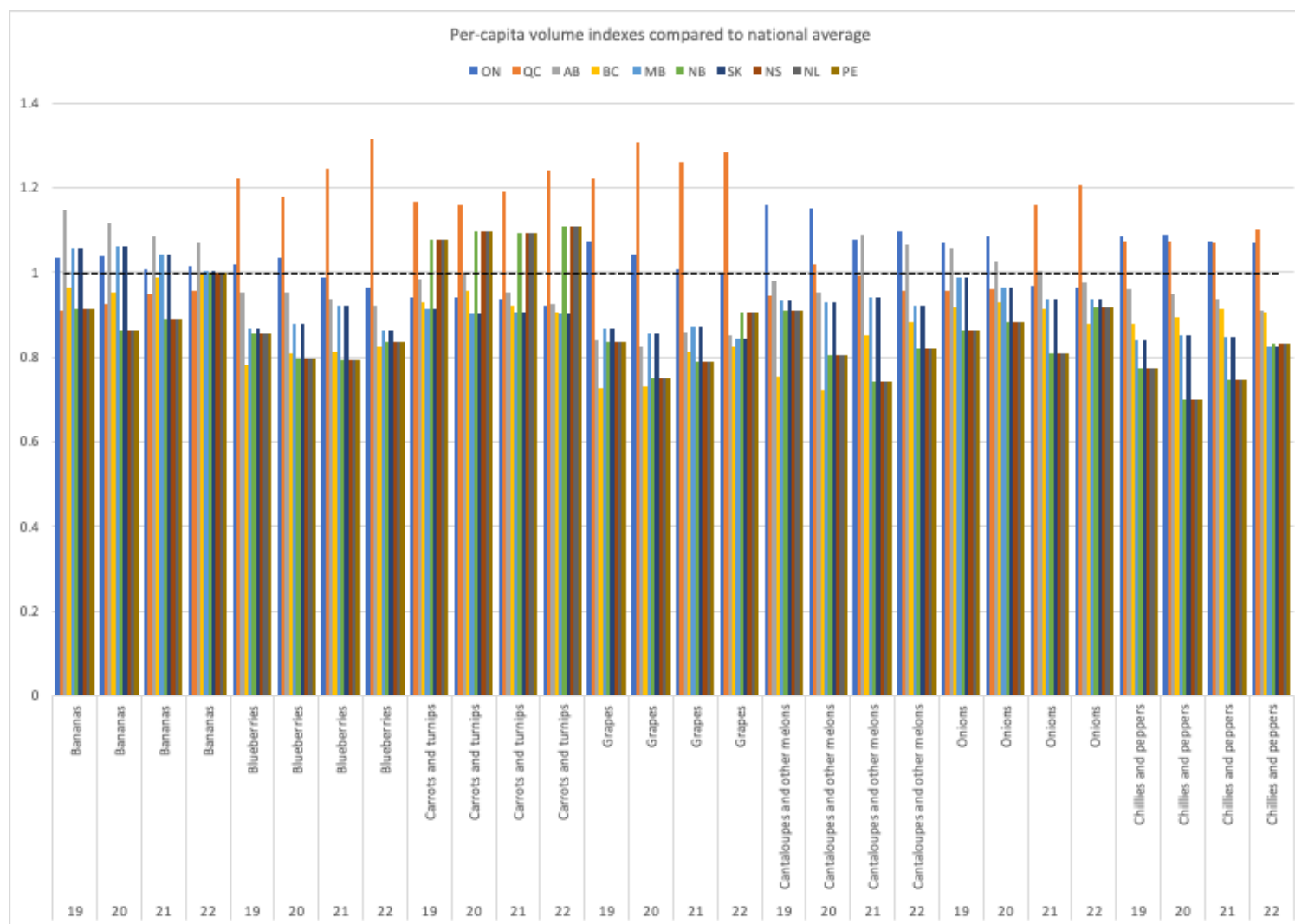


Figure S 23. Per-capita volume index for Canadian provinces compared to national average. The index show the regional differences in demand for bananas, blueberries, carrots and turnips, grapes, Cantaloupes and melons, onions, and chillies and peppers. The index is based on Nelson’s sales data and were estimated by AAFC. The aggregated indices were provided to the author on request

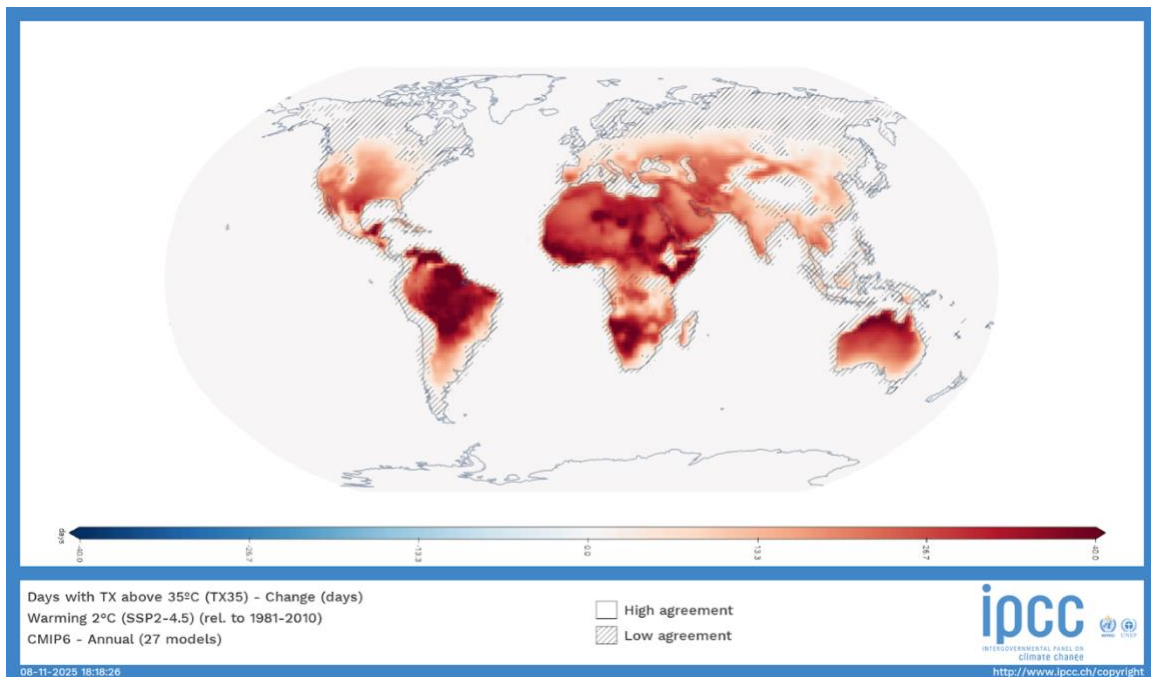


Figure S24: Change in number of days above 35°C across 27 models, taken from IPCC Interactive Climate Atlas (Gutiérrez et al., 2021; Iturbide et al., 2022).

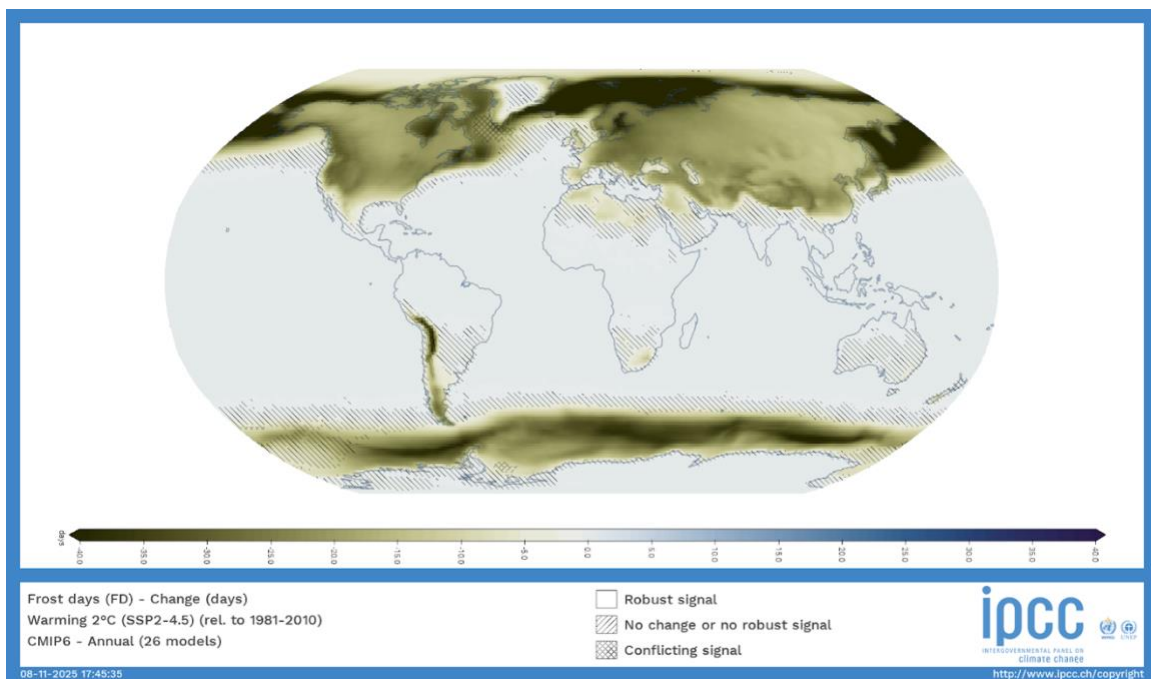


Figure S25: Change in number of days below 0°C across 26 models, taken from IPCC Interactive Climate Atlas (Gutiérrez et al., 2021; Iturbide et al., 2022).

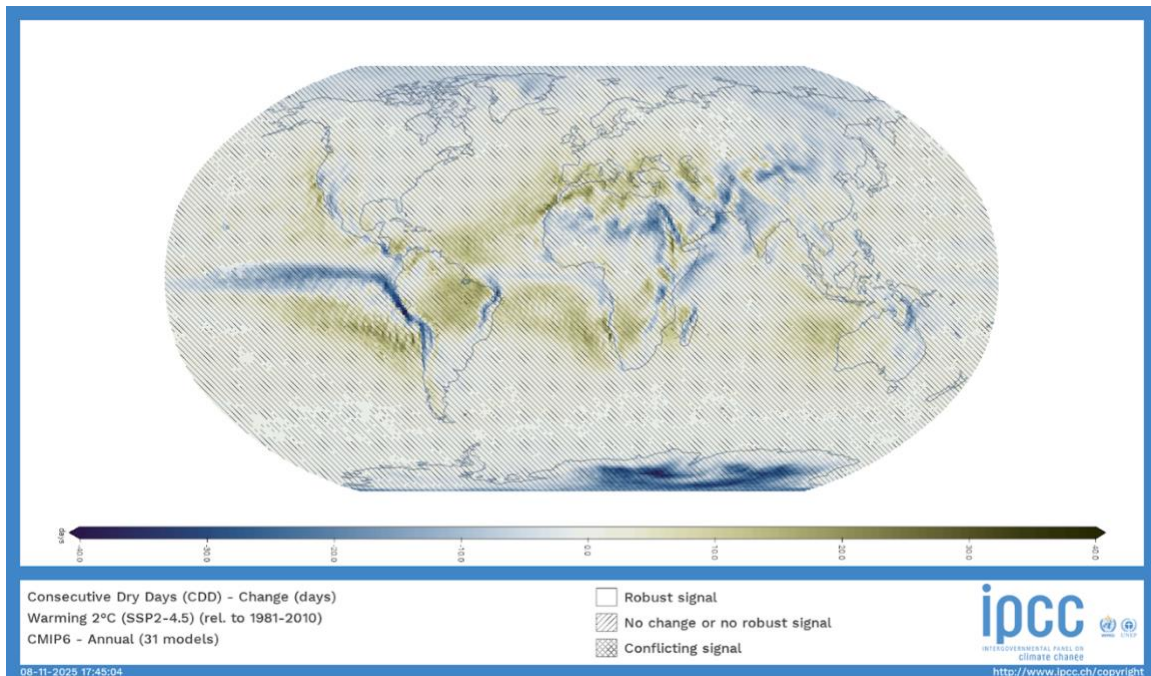


Figure S26: Median change in percentage of consecutive dry days across 31 models, taken from IPCC Interactive Climate Atlas (Gutiérrez et al., 2021; Iturbide et al., 2022).

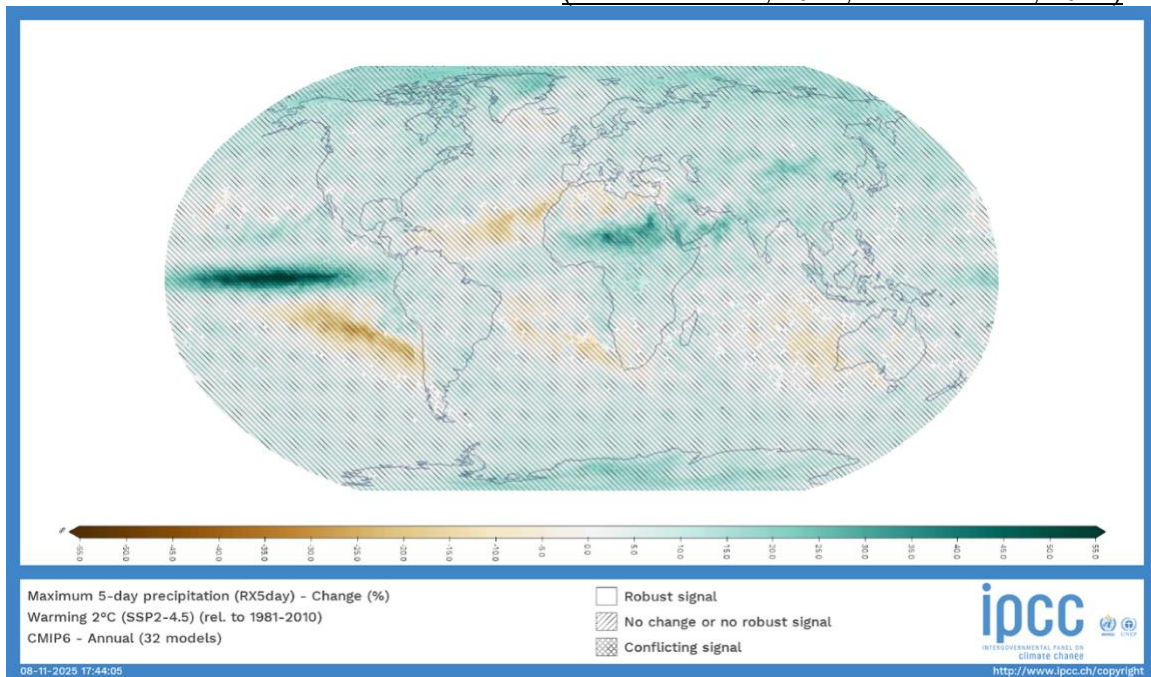


Figure S27: Median change in percentage of 5-day precipitation across 32 models, taken from IPCC Interactive Climate Atlas (Gutiérrez et al., 2021; Iturbide et al., 2022).

Table S 1. Sensitivity of fruits and vegetables to weather extremes. The table characterizes fruits and vegetables based on their sensitivity to too hot (heatwave) and too cold (frost) extremes used in our analysis. The characterization is based on ideal growing temperatures or critical low and high temperatures. Fruits and vegetables with critical temperatures above 35°C or maximum optimum temperature above 30°C are characterized as having no tolerance to too hot extremes. And, fruits and vegetables with critical low temperature or highest freezing temperature during storage above -1°C are characterized to have no tolerance to too cold extremes.

	Too cold	Too hot
Lettuce	No Tolerance (Whiteman, 1957, as cited in Synyder & Melo-Abreu, 2005; Burrows, 2021)	No Tolerance (Choi et al., 2000 as cited in Aleem et al., 2020)
Cauliflower	Somewhat Tolerant (Burrows, 2021)	No Tolerance (Warland et al., 2006 as cited in Aleem et al., 2020)
Onions	No Tolerance (Whiteman, 1957, as cited in Synyder & Melo-Abreu, 2005; Burrows, 2021)	No Tolerance (Bisbis et al., 2018)
Tomatoes	No Tolerance (Whiteman, 1957, as cited in Synyder & Melo-Abreu, 2005; Burrows, 2021)	No Tolerance (As cited in Pathak et al., 2018 and Aleem et al., 2020)
Garlic	No Tolerance (Burrows, 2021)	No Tolerance (As cited in Pathak et al., 2018)
Spinach	No Tolerance (Whiteman, 1957, as cited in Synyder & Melo-Abreu, 2005; Burrows, 2021)	No Tolerance (As cited in Pathak et al., 2018)
Asparagus	No Tolerance (Whiteman, 1957, as cited in Synyder & Melo-Abreu, 2005)	-
Peas	Somewhat Tolerant (Burrows, 2021)	No Tolerance (Devi et al., 2022)
Potatoes	No Tolerance (Whiteman, 1957, as cited in Synyder & Melo-Abreu, 2005; Burrows, 2021)	No Tolerance (Zhang et al., 2021)
Cabbage	Somewhat Tolerant (Burrows, 2021)	No Tolerance (As cited in Pathak et al., 2018)
Limes	Somewhat Tolerant (Whiteman, 1957, as cited in Synyder & Melo-Abreu, 2005)	Somewhat Tolerant (Guha, 2022)
Squash	No Tolerance (Burrows, 2021)	-
Carrots	Somewhat Tolerant (Whiteman, 1957, as cited in Synyder & Melo-Abreu, 2005; Burrows, 2021)	No Tolerance (As cited in Pathak et al., 2018 and Aleem et al., 2020)

Turnips	Somewhat Tolerant (Whiteman, 1957, as cited in Synyder & Melo-Abreu, 2005 Burrows, 2021)	No Tolerance (As cited in Pathak et al., 2018)
Lemons	Somewhat Tolerant (Whiteman, 1957, as cited in Synyder & Melo-Abreu, 2005)	Somewhat Tolerant (Guha, 2022)
Eggplant	No Tolerance Whiteman, 1957, as cited in Synyder & Melo-Abreu, 2005; Burrows, 2021)	-
Pineapples	Somewhat Tolerant (Whiteman, 1957, as cited in Synyder & Melo-Abreu, 2005)	-
Apples	Somewhat Tolerant (Whiteman, 1957, as cited in Synyder & Melo-Abreu, 2005)	Somewhat Tolerant (Kalcsits et al., 2017;as cited in Moretti et al., 2010)
Avocados	No Tolerance (Lahav & Trochoulis, 1982)	Somewhat Tolerant (As cited in Moretti et al., 2010)
Raspberries	No Tolerance (Whiteman, 1957, as cited in Synyder & Melo-Abreu, 2005)	-
Kiwi	No Tolerance (Whiteman, 1957, as cited in Synyder & Melo-Abreu, 2005)	-
Strawberries	Somewhat Tolerant (As cited in Synyder & Melo-Abreu, 2005)	Somewhat Tolerant (As cited in Łysiak & Szot, 2023; Garden Oracle, 2023)
Grapes	Somewhat Tolerant (Whiteman, 1957, as cited in Synyder & Melo-Abreu, 2005; Łysiak & Szot, 2023)	-
Oranges	No Tolerance (As cited in Synyder & Melo-Abreu, 2005)	Somewhat Tolerant (Guha, 2022)t
Pears	Somewhat Tolerant (Whiteman, 1957, as cited in Synyder & Melo-Abreu, 2005; Łysiak & Szot, 2023)	-
Bananas	No Tolerance (As cited in Synyder & Melo-Abreu, 2005)	No Tolerance
Melons	No Tolerance (As cited in Synyder & Melo-Abreu, 2005)	Somewhat Tolerant (Calberto Sánchez et al., 2015)
Mandarins	No Tolerance (As cited in Synyder & Melo-Abreu, 2005)	Somewhat Tolerant (Guha, 2022)
Watermelons	No Tolerance (Whiteman, 1957, as cited in Synyder & Melo-Abreu, 2005)	Somewhat Tolerant (As cited in Pathak et al., 2018 and Aleem et al., 2020)
Cranberries	No Tolerance (Whiteman, 1957, as cited in Synyder & Melo-Abreu, 2005)	-

Papaya	No Tolerance (Whiteman, 1957, as cited in Synyder & Melo-Abreu, 2005)	-
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Table S 2. List of primary and derived fruits and vegetables along with matching key.

FAO Code	FAO Name	FnV ID	FAO Name Primary	Primary /Secondary
116	Potatoes	116	Potatoes	0
117	Flour, potatoes	116	Potatoes	1
118	Potatoes, frozen	116	Potatoes	1
122	Sweet potatoes	122	Sweet potatoes	0
120	Potato offals	116	Potatoes	1
358	Cabbages	358	Cabbages	0
367	Asparagus	367	Asparagus	0
372	Lettuce and chicory	372	Lettuce and chicory	0
373	Spinach	373	Spinach	0
388	Tomatoes	388	Tomatoes	0
390	Juice, tomato	388	Tomatoes	1
391	Tomatoes, paste	388	Tomatoes	1
392	Tomatoes, peeled	388	Tomatoes	1
393	Cauliflowers and broccoli	393	Cauliflowers and broccoli	0
394	Pumpkins, squash and gourds	394	Pumpkins, squash and gourds	0
399	Eggplants (aubergines)	399	Eggplants (aubergines)	0
401	Chillies and peppers	401	Chillies and peppers	0
403	Onions	403	Onions	0
406	Garlic	406	Garlic	0
417	Peas, green	417	Peas, green	0
426	Carrots and turnips	426	Carrots and turnips	0
486	Bananas	486	Bananas	0
490	Oranges	490	Oranges	0
491	Juice, orange, single strength	490	Oranges	1
492	Juice, orange, concentrated	490	Oranges	1
495	Tangerines, mandarins, clementines	495	Tangerines, mandarins, clementines	0
497	Lemons and limes	497	Lemons and limes	0
515	Apples	515	Apples	0

518	Juice, apple, single strength	515	Apples	1
519	Juice, apple, concentrated	515	Apples	1
521	Pears	521	Pears	0
531	Cherries	531	Cherries	0
534	Peaches and nectarines	534	Peaches and nectarines	0
536	Plums and sloes	536	Plums and sloes	0
537	Plums dried (prunes)	536	Plums and sloes	1
544	Strawberries	544	Strawberries	0
547	Raspberries	547	Raspberries	0
560	Grapes	560	Grapes	0
562	Juice, grape	560	Grapes	1
567	Watermelons	567	Watermelons	0
568	Cantaloupes and other melons	568	Cantaloupes and other melons	0
572	Avocados	572	Avocados	0
574	Pineapples	574	Pineapples	0
575	Pineapples canned	574	Pineapples	1
576	Juice, pineapple	574	Pineapples	1
580	Juice, pineapple, concentrated	574	Pineapples	1
592	Kiwi fruit	592	Kiwi fruit	0
600	Papayas	600	Papayas	0
498	Juice, lemon, single strength	497	Lemons and limes	1
499	Juice, lemon, concentrated	497	Lemons and limes	1
558	Other berries and fruits of the genus vaccinium n.e.c.	552	Blueberries	1
523	Quinces	521	Pears	1
552	Blueberries and cranberries	552	Blueberries and cranberries	0

Table S 3. Matching key for FAO codes and HS codes.

FnV_ID	Item	HS06 Code
116	Potatoes	70110, 70190, 71210, 200520, 200410
117	Flour, potatoes	110510, 110520
118	Potatoes, frozen	71010
120	Potato offals	230800
122	Sweet potatoes	71420
358	Cabbages and other brassicas	070420, 070490
367	Asparagus	70920
372	Lettuce and chicory	070511, 070519, 070521, 070529
373	Spinach	70970

388	Tomatoes	70200
390	Juice, tomato	200950
391	Tomatoes, paste	200290
392	Tomatoes, peeled	200210
393	Cauliflowers and broccoli	70410
394	Pumpkins, squash and gourds	70993
399	Eggplants (aubergines)	70930
401	Chillies and peppers	70960
403	Onions	70310
406	Garlic	70320
417	Peas, green	70810
426	Carrots and turnips	70610
486	Bananas	80300
490	Oranges	80510
491	Juice, orange, single strength	200911, 200912
492	Juice, orange, concentrated	200911, 200919
495	Tangerines, mandarins, clementines, satsumas	80520
497	Lemons and limes	200930, 80550
515	Apples	81330, 80810
518	Juice, apple, single strength	200970, 200971
519	Juice, apple, concentrated	200979
521	Pears	80820
531	Cherries	80920
534	Peaches and nectarines	80930
536	Plums and sloes	80940
537	Plums dried (prunes)	81320
544	Strawberries	81010
547	Raspberries	81020
552	Blueberries	81040
560	Grapes	80610
562	Juice, grape	200961, 200969
567	Watermelons	80711
568	Melons, other (inc.cantaloupes)	80719
572	Avocados	80440
574	Pineapples	80430
575	Pineapples canned	200820
576	Juice, pineapple	200941
580	Juice, pineapple, concentrated	200949
592	Kiwi fruit	81050
600	Papayas	80720

496	Juice of tangerine	200931
628	Feed, pulp of fruit	230800
498	Juice, citrus, single strength	200931
499	Juice, citrus, concentrated	200939
523	Quinces	80820

Table S 4. Matching key for FAO codes and NAPC codes.

Item	FnV ID	NAPC Code
Apples	515	114114111
Bananas	486	1141131
Watermelons	567	114221411
Oranges	490	1141121
Grapes	560	1141147
Cantaloupes and other melons	568	114221421
Blueberries and cranberries	552	1141114
Blueberries and cranberries	552	114111311
Tangerines, mandarins, clementines	495	1141121
Strawberries	544	114111111
Pineapples	574	1141132
Pears	521	114114211
Peaches and nectarines	534	114114411
Peaches and nectarines	534	114114412
Raspberries	547	114111211
Pomelos and grapefruits	507	1141122
Cherries	531	114114511
Plums and sloes	536	1141143
Kiwi fruit	592	1141115
Papayas	600	1141134
Potatoes	116	1142111
Carrots and turnips	426	11422111
Carrots and turnips	426	11422112
Onions	403	114221211
Onions	403	11422123
Lettuce and chicory	372	11422131
Cabbages	358	11422132
Tomatoes	388	11422151
Cauliflowers and broccoli	393	114221831
Cauliflowers and broccoli	393	114221821
Pumpkins, squash and gourds	394	114221551

Pumpkins, squash and gourds	394	114221561
Lemons and limes	497	1141122
Avocados	572	1141134
Peas, green	417	114221611
Chillies and peppers	401	114221541
Sweet potatoes	122	114221161
Spinach	373	114221341
Asparagus	367	114221351
Eggplants (aubergines)	399	114221571
Green garlic	406	114221221

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