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Canada's fruit & vegetable supply at sub-national scale: A first step to understanding vulnerabilities to climate change

A *Research* Report prepared for CAPI
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Research
Report

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To ensure the validity and quality of its work, CAPI requires all *Research* Reports to go through a peer review process. CAPI thanks the Doctoral Fellows Mentors who provided expertise, guidance, and feedback on these reports throughout the first year of this fellowship: Aaron Cosbey, Cam Dahl, Dr. Karen Hand, and Dr. Lenore Newman. The views and opinions expressed in this paper are solely those of the authors and do not necessarily reflect those of CAPI.

Note from CAPI

CAPI recognizes the importance of fostering and mentoring the next generation of thought leaders emerging from Doctoral programs across Canada, who are working in multi-disciplinary fields. Through this program, CAPI offers a small, innovative group of young students the opportunity to apply their newfound knowledge and expertise to some of agriculture's most critical policy issues.

The third cohort of CAPI Doctoral Fellows (2022-2024) was tasked with focusing their research on the intersection of agricultural trade, the environment and food security and this paper is one of the results. In light of recent trade disruptions, food security concerns and climate change commitments, CAPI is interested in how they are impacting Canadian agriculture and agri-food and the policy implications. This paper is the first deliverable in the first year of the two year program, showcasing the interdisciplinary nature of the fellows' research as it relates to Canada's fruit and vegetable trade, its role in Canada's vulnerability to climate change and policies needed to address this.

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Key Takeaways

- Mapping the supply of fruits and vegetables at high resolution is essential to understanding Canada's vulnerabilities to climate change and other non-climatic shocks in this sector. More granular data can help improve this understanding.
- Certain provinces act as supply hubs where large quantities of fruits and vegetables enter Canada and are cleared through customs before being distributed to neighbouring provinces or across the country for consumption. Investing in domestic transportation and storage infrastructure in these regions is, therefore, essential to facilitate undisrupted flows across Canada. The recent supply disruptions from flooding in British Columbia in 2021 underscore the importance of investments in domestic infrastructure.
- Understanding the least and most vulnerable nodes in the supply of fruits and vegetables to Canada and specific provinces can help identify where to diversify supply sources to ensure Canadian consumers have access to a wide assortment of affordable fruits and vegetables essential for healthy diets. Promoting fair trade rules and trade agreements with a diversity of countries will increase the sector's resilience.
- Supporting small-scale fruit and vegetable producers, greenhouse operators and processors across Canada can increase domestic production and promote competitiveness of these commodities. This could reduce substantial reliance on a few international producing regions that make Canada vulnerable.
- Canada can increase the resilience of its fruits and vegetable supply by investing in research for more climate resilient products, technologies and farming practices that will help producers adapt to changing weather and climate risks.

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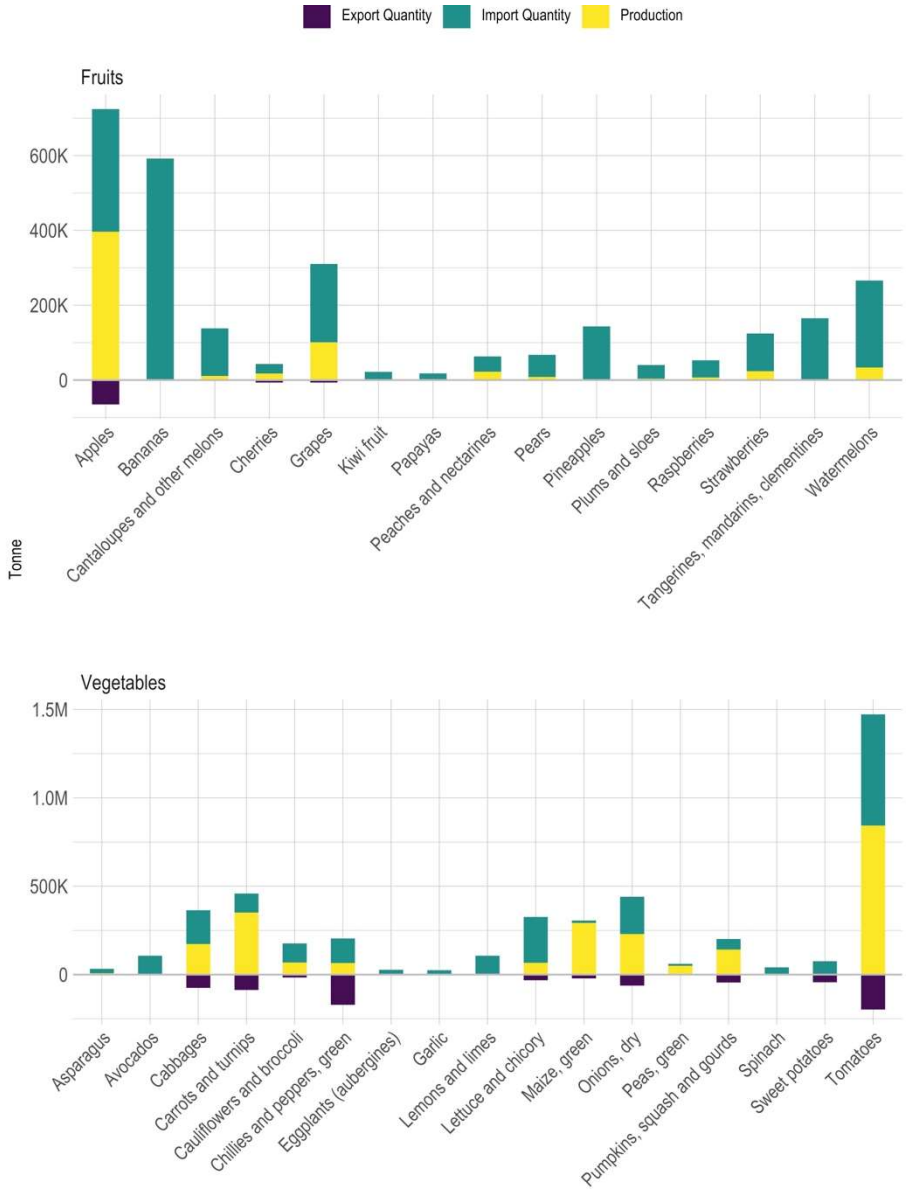
Introduction

Fruits and vegetables are an integral part of having a healthy diet. Canada's food guide, released in 2019, recommends that half of our daily food intake should be comprised of fruits and vegetables (Health Canada, 2019). The food guide also recommends that adults should consume at least 7-8 servings of fruits and vegetables per day, with a serving size of ½ cup of cooked or canned vegetables or fruit, or 1 cup of raw leafy vegetables. To make this a reality, the availability of- and affordable access to- fruits and vegetables is key.

Despite the known benefits, only a small percentage of Canadians buy sufficient fruits and vegetables to meet the recommendations set out by the Canada Food Guide(Charlebois et al., 2023). At the same time, the availability of fruits and vegetables for consumption has declined over the last ten years(Government of Canada, 2022a). Furthermore, according to a recent survey, the costs of fruits and vegetables along with a lack of knowledge and appropriate preparation skills are the leading drivers of low fruit and vegetable consumption in the country (Charlebois et al., 2023). With increasing weather shocks and global warming availability and cost issues are set to worsen if not appropriately addressed.

Canada's fruit and vegetable supply is largely dependent on international trade and, thus, must be considered separately to the risks and opportunities that climate change poses to the domestic Canadian agri-food sector.The connectivity through agri-food trade enables countries, including Canada, to meet the nutritional needs of hundreds of millions of people (Wood et al., 2018). For this reason, trade is essential. However, any shock in producing regions or to supply routes can manifest in shortages or increasing costs of fruits and vegetables. There are multiple recent and well-recognized examples of such cross-border supply shocks and their reverberating impacts across the world: the geopolitics of blockades on Ukrainian grain and the unavailability and costs of fertilizers globally. As prices rose, we saw wheat export bans from India amidst heat waves and palm oil export bans from Indonesia. Similar export bans took place during the 2007-8 and 2010-12 food crises. Closer to home, the recent shocks to romaine lettuce supply and prices caused by a pathogen outbreak and flooding in California exemplify the importance of supply chain resilience of our fruits and vegetables (Jonas and News ·, 2022). Canada's fruit and vegetable supply disruptions and healthy diet are also vulnerable to cross-border shocks and supply disruptions, particularly because of our substantial reliance on international imports.

Figure 1. Canada's national fruit and vegetable production, import and export for the year 2020. The bars correspond to primary fruits and vegetables included in the analysis. Note, the data includes all derived commodities from primary fruits and vegetables. Derived commodities are converted back to primary fruits and vegetables in this figure.



About 80% of Canada's fruits and 60% of its vegetables are imported from other countries (Fig. 1). A large portion from the United States, Mexico and other Latin American countries (Kissinger, 2012; USDA Foreign Agricultural Service, 2022). This import dependence varies substantially by Canadian province due largely to geographic advantages. Such a heavy reliance on fruit and vegetable imports leaves Canada vulnerable to both climatic and non-climatic shocks in the global food market, such as price spikes or supply chain interruptions caused by natural disasters, political conflicts, or other factors.

To build resilience and ensure the long-term sustainability of the fruit and vegetable supply in Canada, it is critical to understand the supply chain at a provincial level and to develop policies and stakeholder interventions that can address vulnerabilities and mitigate risks. This report investigates Canada's fruit and vegetable supply at a

provincial scale, accounting for derived products and interprovincial flows, and provides insights to support policy or stakeholder interventions.

Data & Approach

To better understand the cross-border climate vulnerabilities of Canada's fruit and vegetable supply, we first need to measure food flows at the provincial scale. A sub-national evaluation can help capture the heterogeneity across Canada's large landmass. Further, this builds an understanding of how much Canadian provinces depend on international imports to meet their consumption, from where this consumption is met, and how it varies across provinces.

> Consumption in this report is defined as the food available for consumption. It is estimated using the supply and utilization accounts and does not represent the amount of food consumed by individuals. The latter is harder to measure and Canada lacks sufficient open-source data to estimate individual consumption for specific fruits and vegetables.

Despite the availability of trade data at the provincial scale from Statistics Canada (Canadian International Merchandise Trade Web Application), measuring provincial level food supply is complicated. This is mainly because the customs-based trade data is based on province of clearance (Statistics Canada, n.d.). Province of clearance is the province in which food enters and is cleared by the customs office when crossing Canadian borders, and does not necessarily mean the province in which food is consumed (Statistics Canada, n.d.). Additionally, lack of inter-provincial data on food flows from province of clearance to province of consumption creates a major challenge in understanding and estimating provincial-level food supply. It is important to here note that Canadian Freight Analysis Framework(Statistics Canada, n.d.) data provides some insight into inter-provincial flows; however, these data are not disaggregated by food commodity groups and the integration of these data is out of the scope of this work. In the following section, I describe how I fill this gap by estimating inter-provincial flows based on a simplified mass balancing approach. I use this approach to calculate provincial supply of fruits and vegetables by accounting for inter-provincial flows from province of clearance to province of consumption.

For the analysis in this report, I use three key data sources and have made some assumptions. First, I use the supply-utilization accounts from United Nation's Food and Agriculture Organization (FAO) for national level production, imports and exports data for 16 primary fruits and 17 primary vegetables and their respective derived products (available at www.FAOSTATS.com). Figure 1 shows the fruits and vegetables included in my analysis and the national production, import and export estimates after derived commodities are converted back to primary fruits and vegetables. Second, I use bilateral trade data for the same fruits and vegetables collated and distributed by Statistics Canada (available through the Canadian International Merchandise Trade Web Application). This is customs-based data and provides detailed information on provincial level imports from and exports to each state in the United States, along with data to and from every other country. As the United States is Canada's largest trading partner, this high-resolution data provides a comprehensive assessment of trade dependence at a sub-national scale. Third, I use data on domestic production of fruits and vegetables for each province, collected by Agriculture and Agri-Food Canada and distributed by Statistics Canada. This is based on Fruits and Vegetable Surveys conducted every year to estimate the total cultivated area, harvested area, total production, marketed production and farm gate value of fruits and vegetables grown in Canada (Government of Canada, 2022b).

Harmonizing the data

In order to estimate provincial-level supply, I first harmonized the three datasets. Each dataset uses a different classification system. The FAO supply-utilization accounts uses either the FAO Commodity List or the new Central Product Classification (CPC) classification system (Ramaschiello, 2015). The provincial-level customs-based trade data uses Harmonization System (HS) classification, a standard practice in international

trade data. And, the provincial-level production data uses the North American Product Classification System (NAPCS).

In order to harmonize the three classification systems, I first converted the derived fruit and vegetable back to their associated primary fruits and vegetables. I did this by using conversion factors based on caloric content of derived and primary fruits and vegetables. For example, data on apple juice is converted back to apples and aggregated together as apples. Similarly, tomato sauce and tomato paste are converted back to tomatoes. As such, a total 23 fruits and 23 vegetables commodities are included in this analysis. These represent 16 primary fruits and 17 primary vegetables.

Once converted back to primary commodities, I matched the primary fruit and vegetable classification codes across the three different sources. I did this by using a matching key created based on the descriptions of each fruit and vegetable commodity in the three classification systems. To check the harmonization and conversion process, I compared the total imports from the food balance sheet data (used to estimate consumption) and total imports from customs-based trade data at national scale. I find that for all fruits and vegetables except potatoes and oranges, the harmonization error is minimal. As such, I remove potatoes and oranges from further analysis and combined the rest into fruits and vegetables categories to derive sector-level insights.

Estimating consumption at provincial scale

To estimate provincial-level consumption, I use national estimates on production, imports, and exports of fruits and vegetables from the FAO's supply-utilization accounts. I used this data along with population estimates to calculate a rather simplified measure of national per-capita consumption (production + imports – exports). Note, I do not account for any food waste, loss or stock changes in the consumption calculations. This is to avoid any additional sources of uncertainty in the consumption and inter-provincial calculations. Ideally, adding provincial-level food waste, loss or stock changes would improve my calculation. However, this is out of the scope of this study.

Next, I estimated provincial-level consumption of each fruit and vegetable assuming per-capita provincial consumption is the same as per-capita national consumption. To corroborate this assumption, I compared household expenditure survey data across provinces. I find, on average, household expenditure compared to total food expenditure in 2019 is comparable across provinces and national estimates (see Appendix I).

Estimating interprovincial flows

In order to estimate interprovincial flows, I use a simple accounting approach that includes interprovincial flows as illustrated in the equation below:

$$Consumption = Production + Net\ Imports_{international} + Net\ Interprovincial\ flows$$

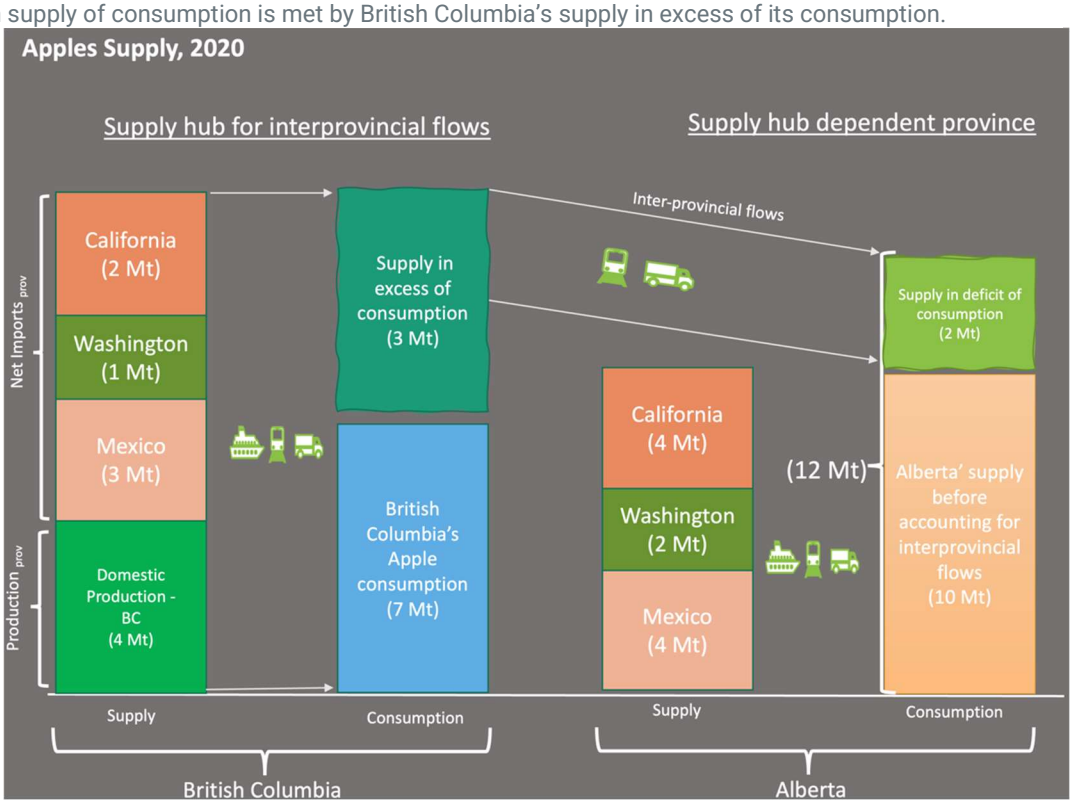
With the harmonized data for provincial-level consumption, provincial-level imports and exports, and provincial-level production, I use the above equation to estimate the net interprovincial flows for every province, and the two fruit and vegetable categories.

Interprovincial flows can be either inward or outward in direction. Outward interprovincial flows indicate the supply that is in excess of the provincial consumption. Provinces with outward interprovincial flows are called supply hubs. On the other hand, inward interprovincial flows are the deficit in supply required to meet the provincial consumption. The provinces with inward interprovincial flows are called hub-dependent provinces.

Figure 2 graphically illustrates this using an example of British Columbia and Alberta's hypothetical apple supply. In this figure, British Columbia acts as a supply hub as its supply from within province production and

international imports is in excess of its consumption. Coversely, Alberta is a hub-dependent province because its supply from within-province production and international imports is in deficit of its consumption.

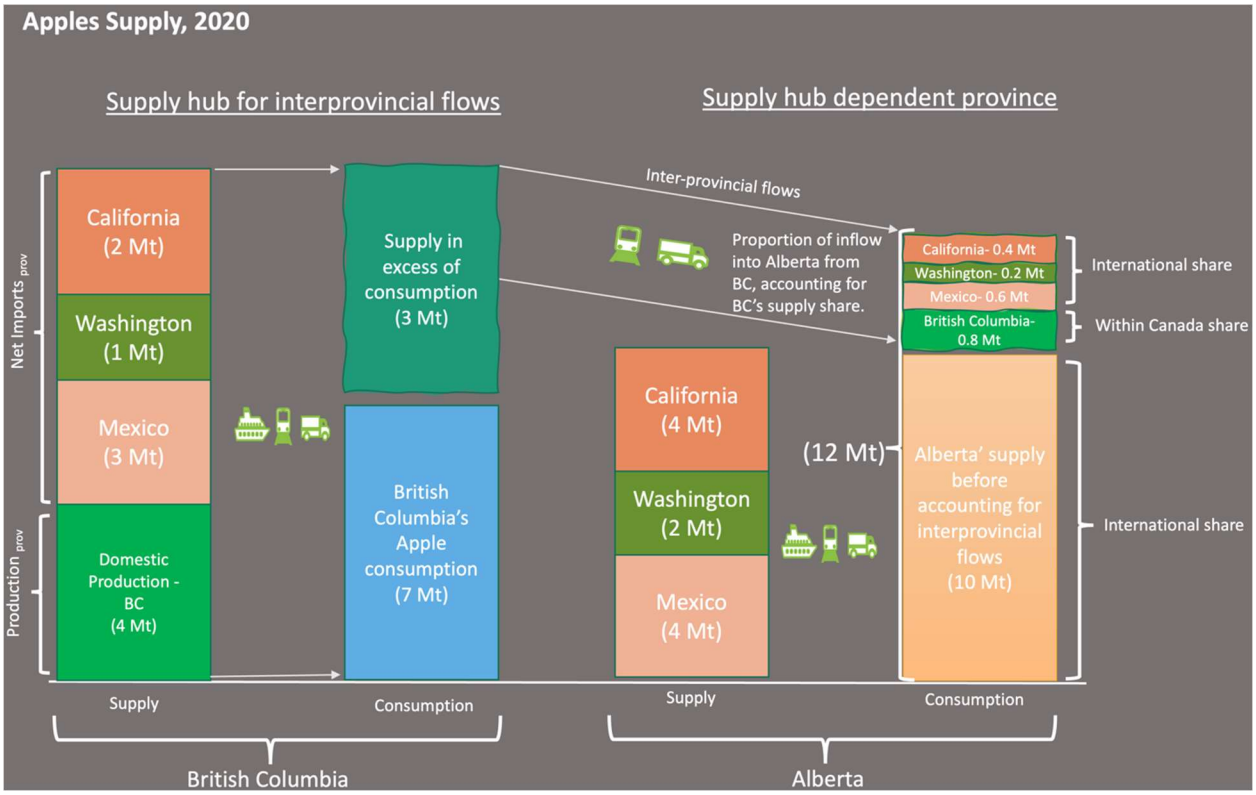
Figure 2. Graphical illustration of supply hubs and hub dependent provinces. The figure shows how Alberta's deficit in supply of consumption is met by British Columbia's supply in excess of its consumption.



Balancing inward and outward interprovincial flows

Once the inward or outward interprovincial flows are calculated, I created new inter-provincial links between the supply hubs to import-dependent provinces to balance the above equation. I did this by distributing any supply in excess of consumption from the supply hubs to provinces in deficit of supply to meet their consumption needs. The distribution is first done within western (British Columbia, Alberta, Saskatchewan and Manitoba), eastern (Quebec, Ontario and Newfoundland & Labrador), and maritime regions (New Brunswick, Nova Scotia and Prince Edward Island). Any leftover excess is then distributed from supply hubs to hub-dependent provinces across these regions. Figure 3 graphically illustrates the new interprovincial links generated between British Columbia (supply hub) and Alberta (hub-dependent province).

Figure 3. Graphical illustration of how interprovincial flows are traced back to the producing regions in the analysis.



While this distribution process provides insights into how much various provinces are dependent on international versus inter-provincial flows for their supply, I went a step further and redistributed the inter-provincial flows back to the producing regions. I did this by readjusting interprovincial flows using supply shares of the supply hubs. For example, if interprovincial flow of apples from British Columbia's (supply hub) to Alberta (hub dependent province) 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 (Fig. 3).

Results

Canada's fruit & vegetable supply

At a national scale, when derived commodities are converted back to primary fruits and vegetables, I observed that apples (0.66 Mt), bananas (0.59 Mt) and grapes (0.30 Mt) ranked the highest in terms of total quantities of fruits supplied to Canada in 2020. These are followed by watermelons (0.26 Mt) and pineapples (0.14 Mt) (Fig. 1). Note, oranges which are not included in my analysis, are also among the highest consumed fruits.

In the vegetable category, tomatoes (1.3 Mt), onions (0.4 Mt), carrots and turnips (0.37 Mt) rank the highest. These are followed by chillies and peppers (0.33 Mt), green maize (0.28 Mt), lettuce and chicory (0.29 Mt), cauliflower and broccoli (0.16 Mt), and pumpkins, squash and gourds (0.16 Mt). The remain vegetables are consumed in rather small quantities (Fig. 3).

My analysis finds that Canada is highly dependent on imports for its supply of fruits and vegetables and their derived products (Fig. 4). Further, I find that Canada's import dependence[1] for fruits and vegetables in the year 2020 was 79.8% and 58.2%, respectively. The import dependence for fruits has remained relatively stable since 2010, with little fluctuations throughout the years. However, Canada's import dependence for its vegetable supply has increased by roughly eight percent (from 50.7% to 58.2%) in the last decade. Note, these estimates are not solely based on fresh fruits and vegetables and account for all derived commodities, such as juices, canned fruits and vegetables, etc.

I also note that Canada's import dependence varies substantially across different fruits and vegetables (Fig. 5). For all fruits except apples, peaches and nectarines, grapes, and cherries, Canada relies on international imports for over 80% of its national supply. Roughly 50% of apples, 70% of peaches and nectarines, 75% of grapes, and 75% of cherries are sourced internationally.

1 Import dependence is defined as the share of total supply that is met through international imports.

Figure 4. Canada's national import dependence for fruits and vegetables supply from 2010 to 2020. All fruits and vegetables included in the analysis are aggregated into two categories.

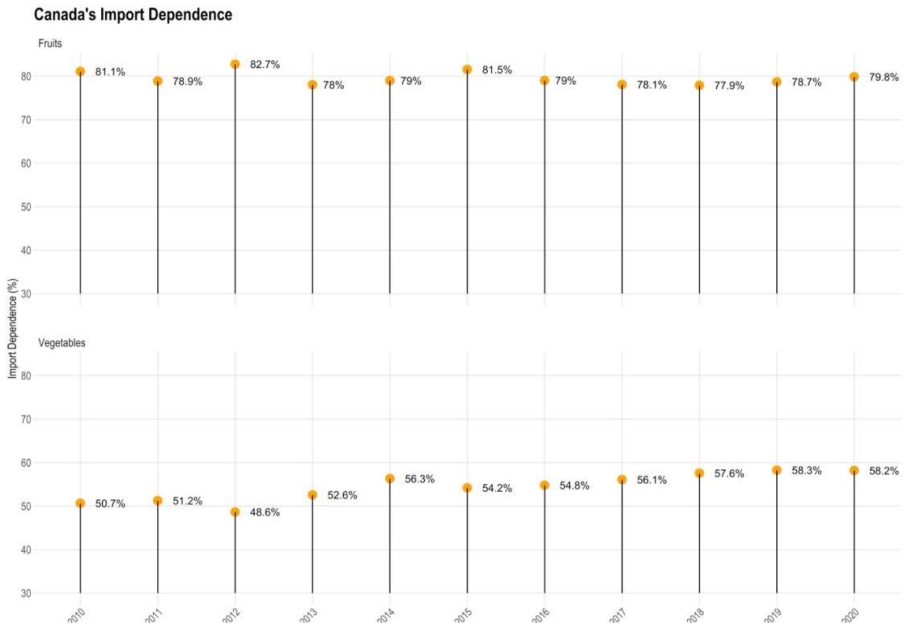
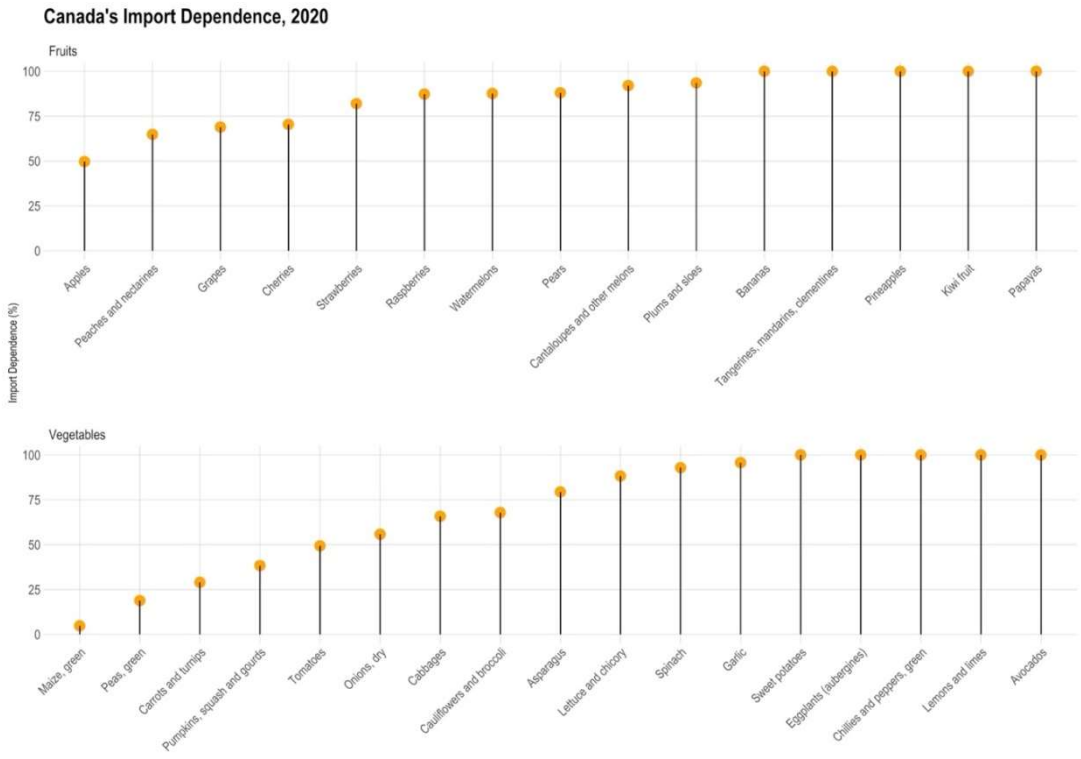


Figure 5. Canada's national import dependence for each fruit and vegetable included in the analysis. The values are for the year 2020.



In case of vegetables, my analysis found more variation in import dependence than for fruits (Fig. 5). Import dependence varies from as high as 100% to as low as 10%. Canada is almost entirely dependent on international imports for avocados, garlic, lemons/limes, peppers, eggplant, spinach and sweet potatoes. In case of tomatoes, despite Canada producing over 0.84 million tonnes of tomatoes in 2020, its import dependence remains around 50%. Note, some of this can be attributed to derived tomato products, such as canned tomatoes and pasta sauce, that Canada imports in large quantities. For potatoes (not included in the interprovincial analysis), Canada is self-reliant. It produced over 6.4 million tonnes of potatoes in 202, out of which approximately 1.6 million tonnes were exported while the rest were consumed domestically. For green peas, carrots and turnips, pumpkins, squash, and gourds, Canada's import dependence is less than 40%.

Supply hubs and hub-dependent provinces

In order to understand how food flows from its province of clearance to province of consumption in Canada, I estimate the inward and outward interprovincial flows for each province aggregated for fruits and vegetables (as explained in the data and approach section above).

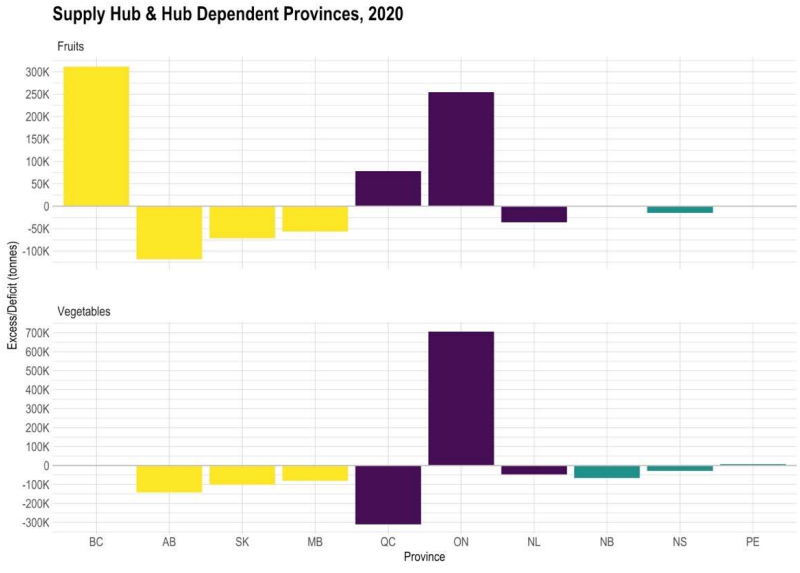
Figure 6 shows the provinces with supply in excess of their consumption (supply hubs) and the provinces with supply in deficit of their consumption (hub-dependent) aggregated for fruits and vegetables for the year 2020. My analysis found that Ontario, British Columbia and Quebec act as supply hubs of fruits. I find that 311 thousand tonnes (Kt), 254 Kt and 71 Kt of fruits land in Ontario, British Columbia and Quebec, respectively, is in-excess of their respective consumption and is likely distributed to the neighboring provinces as interprovincial flows. Alternately, for the prairie provinces of Alberta, Manitoba and Saskatchewan, the supply of fruits is in deficit of their consumption (hub-dependence) by 118 Kt, 0.56 Kt and 67 Kt respectively. Nova Scotia, and New Brunswick are also hub-dependent, with their consumption likely met by 51 Kt and 6.7 Kt of interprovincial flows of fruits. In the case of vegetables, I found that Ontario is the main supply hub with roughly 706 Kt of vegetables being cleared by customs in the province in-excess of its consumption. As such, most interprovincial flows move from Ontario to other provinces where they are intended to be consumed. It is important to note the hubs and hub-dependent provinces may vary by specific fruits and vegetables.

The existence of supply hubs and hub-dependent provinces in Canada is not surprising. These are a result of geographic (proximity to producing regions), infrastructure, and institutional structures. For example, Ontario, Quebec and British Columbia have the largest international border entry points and clear the most freight in Canada (Transportation Canada, 2020). In addition, most fruit and vegetable processing facilities in Canada are located in these three provinces. As of 2021, roughly 39% of all Canadian fruit and vegetable processing establishments were located in Ontario (226 out of 581), followed by Quebec and British Columbia which constitute 25% and 16% of all fruits and vegetable processing establishments, respectively (Table 1).

Table 1. Number of fruit and vegetable processing establishments by Canadian province in 2021 (ISED, 2021).

Province/territory	Employers	Non-employers / Indeterminate
Ontario	126	100
Quebec	92	51
British Columbia	54	37
Alberta	33	22
Nova Scotia	10	8
New Brunswick	10	5
Saskatchewan	8	3
Prince Edward Island	7	3
Manitoba	8	2
Newfoundland and Labrador	2	0
Northwest Territories	0	0
Nunavut	0	0
Yukon	0	0
Canada	350	231

Figure 1. The figure shows the provinces that act as supply hubs and the ones that are dependent on supply hubs. The y axis shows the quantity (in tonnes) of supply in excess of consumption (positive values) and supply in deficit of consumption (negative values). The provinces are colored based on regions. Western provinces in yellow, eastern in purple and maritime in green. Within region distribution is given preference while distributing food from provinces with excess to provinces with deficits.



Import dependence of Canadian provinces

By attributing interprovincial food flows back to the producing regions (as explained in the data and approach section), I estimated the share of fruit and vegetable supply that is met through within-province production, within Canada, and internationally (from other countries) (Fig. 7). For fruit, I find that the dependence on international imports varies from 32.9 % (Nova Scotia) to 95.6% (Ontario). Supply from within Canada ranges from less than 1% (Ontario, British Columbia and New Brunswick) to 23.7% (Saskatchewan). And supply share from within-province supply from less than 1% (the three prairie provinces, Newfoundland and Labrador) to 58.2% (Nova Scotia).

In the case of vegetables, I found that the reliance on international imports ranges from as low as 11.7 % (Nova Scotia) to 82.2% (New Brunswick). For the western provinces, 77.1% of British Columbia's, to 68.9% of Alberta's, 50.2% of Saskatchewan's and 57.5% of Manitoba's supply is met through international imports. For the prairie provinces, the rest of their supply is entirely met by vegetables sourced from other provinces within Canada. That being said, within province-supply contributes to 22.7% of British Columbia's total vegetable supply. This is less than Quebec and Ontario, where I estimate the within-province supply contributes to 49.9% and 38.8% of their respective supplies. The rest of Quebec and Ontario's supply is mainly met from international imports i.e., 35% and 61.2% respectively.

Figure 2. The share of fruits and vegetable supply that is met through within province, within Canada, and internationally (from other countries) for every province and the year 2020. Each bar represents a province, as labelled on the x-axis. The stacks and the numbers within each stack represent the percentage of total supply met through domestic production (in purple), food sourced from other provinces within Canada (in green) and internationally (in yellow). The dashed lines represent national average import dependence before interprovincial flows are accounted for.

Provincial supply portfolios

By redistributing interprovincial flows back to producing regions, I mapped the fruits and vegetable supply portfolios for each province in the year 2020. Figure 8 shows the provinces on the y-axis and the supply proportion on the x-axis. Each stack within the bar corresponds to the producing regions where the province sources its fruits and vegetables from.

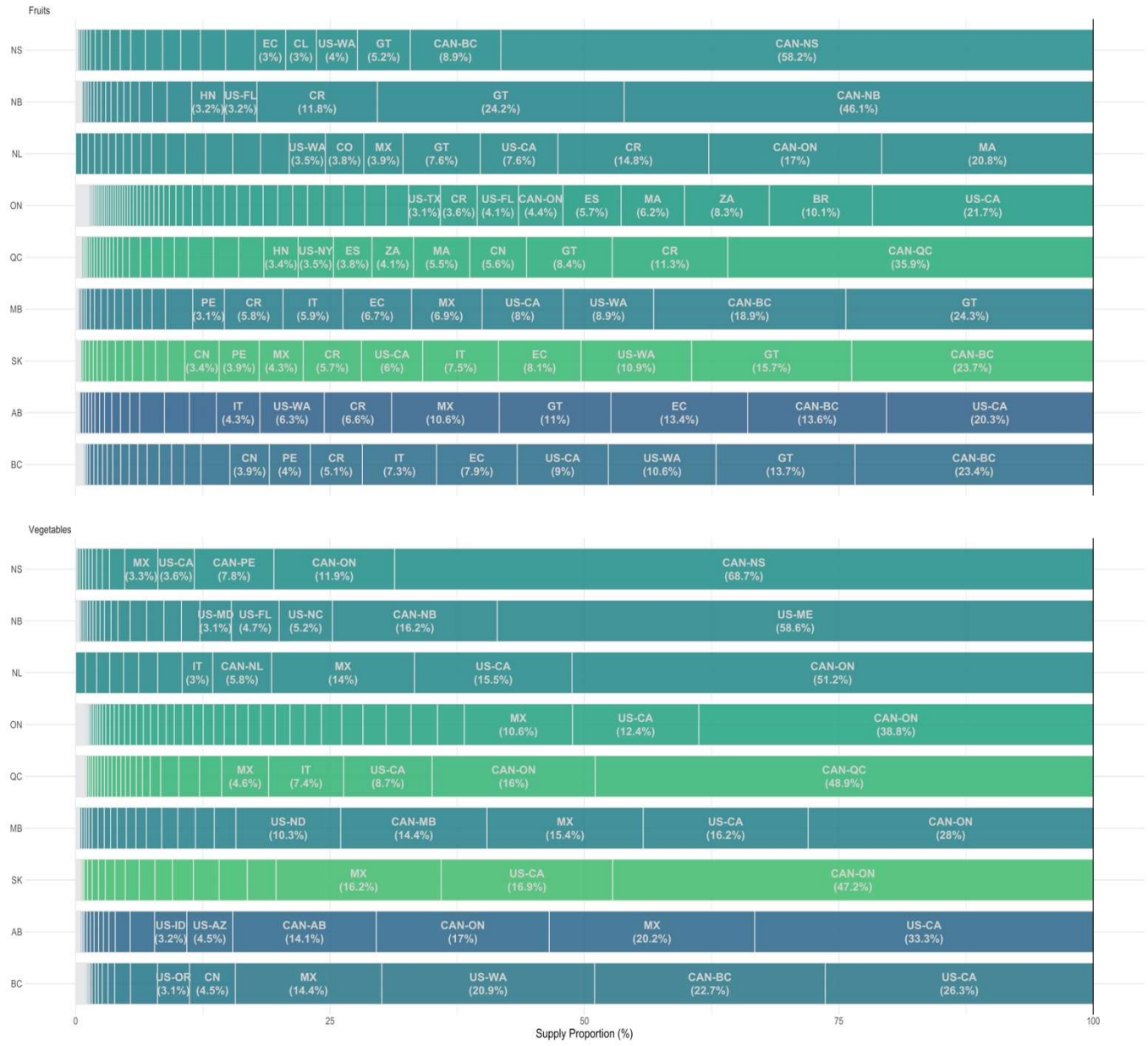
When fruits are aggregated (as done in my analysis), I find the diversity of Canada's fruit supply is high. Canadian provinces source fruits from different countries across North, Central and South Americas and from a few countries in Africa and Europe. Almost all provinces source some proportion of their fruits from Costa Rica and Guatemala. However, it is important to note that diversification in fruit supply varies substantially when specific fruits are considered. For example, Canada sources most of its bananas from only four countries i.e., Peru, Ecuador, Costa Rica and Columbia, and almost all of its avocados from Mexico.

I observed less diversity in vegetable supply at the provincial scale when vegetables are aggregated. For example, British Columbia sources roughly 65% of its vegetable supply from three regions outside of Canada i.e., the states of California (26.3%) and Washington (20.9%), and Mexico (14.4%). For most provinces, the majority of vegetables are sourced either within-province, from within Canada or from the United States and Mexico.

However, Ontario stands out as an exception. It sources a large share of its vegetable supply from numerous producing regions, each contributing a small proportion to the total provincial supply (as demonstrated by the number of stacks with small width in figure 8).

I also observed some regional differences in fruit supply portfolios across provinces. Western provinces source more fruit from Ecuador, Washington State, California, Guatemala, Mexico and Italy, whereas the eastern and maritime provinces source more fruits from Morocco, Washington State, South Africa, Brazil, Florida, China and Spain. In the case of vegetables, the regional differences are less prominent. Most provinces rely on within-province supply, production of neighboring provinces or or further afield via California, Washington State and Mexico. A few exceptions include Manitoba which sources roughly 10% of its supply from North Dakota and New Brunswick which gets 58.6% of its supply from the state of Maine. These regional differences can also be more pronounced in the case of specific fruits and vegetables.

Figure 3. Supply portfolios of each province after interprovincial flows are accounted for in the year 2020. Each bar corresponds to a particular province as labelled on the y- axis. Each bar is made up of multiple stacks of different lengths. Each stack corresponds to a particular region (country, states in case of US and provinces in case of Canada) supplying fruits and vegetables to the provinces. The length of each stack (measured on the x-axis) within each bar corresponds to the proportion of total fruit and vegetables supplied to the province. All countries are labelled using the two-letter country classification. The US state and Canada provinces are labelled with the country code and state/province code separated by a hyphen.



Policy Relevance

This detailed understanding of the sub-national supply of fruits and vegetables can be used to understand how much Canada's provincial-level provision of fruits and vegetables is from regions vulnerable to climatic and non-climatic shocks. This can be done by integrating data on climate exposure, vulnerabilities and adaptive capacities of all producing regions that provinces rely on for their fruits and vegetable supply, a possible next step to this preliminary work. Accounting for climate risks of cross-border regions will be important component for improving our understanding of supply chain resilience. However, for a holistic understanding of systemic risks to food supply chains, incorporating other non-climatic risks and their interactions, such as pest and pathogens, socio-economic risks, natural resource depletion, institutional risks, among others, will be critical.

The insights from my sub-national analysis can help inform policy options to increase the resilience of Canada's fruit and vegetable supply to future climate and non-climatic shocks. I highlight a few intervention points below:

- Appraising current and future trade agreements and prioritizing strategies to enhance the resilience of food systems to future climate and non-climatic disruptions. The insights from my work can help identify the least and most vulnerable nodes in the supply of fruits and vegetables to Canada and specific provinces. Incorporating these insights in identifying priorities for trade agreements could create a conducive environment for a more resilient and diversified supply of food to Canada.

- Supporting small-scale fruits and vegetable producers and processors across Canada can increase the domestic production and competitiveness of these commodities. This could reduce substantial reliance on a few international producing regions.

- Increasing greenhouse production of fruits and vegetables could also reduce reliance on far-away producing regions and manage climate risks. However, this should not come at the cost of increasing greenhouse gas emissions from food production further or environmental sustainability of food production.

- Support eat-local food movements that act as levers to increasing domestic production and more sustainable and seasonal foods.

- The insights from my analysis makes a case for Canada to increase funding for adaptation and resilience programs, especially to regions upon which it relies for its food. By helping producers adapt to changing weather and climate risks in far-away regions, Canada can increase the resilience of its fruits and vegetable supply by investing in research for more climate resilient products, technologies and farming practices.

- Access to more granular data on where the food is sourced internationally and where and how it moves within Canada from the major retailers/importers of food can help build a better network model of food flows at the municipal level. This information, along with climate and weather extreme projections, could help identify critical transportation and infrastructure chokepoints and risky flows within Canada and internationally.

- For all provinces, a large share of their fruits and vegetables are supplied through interprovincial flows of food that is either produced in neighboring provinces or across international borders. For provincial and federal governments, investing in domestic transportation and storage infrastructure is important to ensure an undisrupted flow of food within Canada. The recent widespread supply disruptions from flooding in British Columbia underscores the importance of increasing investments for domestic infrastructure.

- For governments, food traders, and retailers, taking a cross-border climate vulnerability perspective can assist in strategic decision-making around long term investments, both domestically and internationally. It can support investment decisions on where and how much to invest in warehouse and transportation infrastructure for a resilient food supply in a shock prone world.

- Lastly, promoting fair trade rules and trade agreements with a diversity of countries can ensure Canadian consumers have access to a wide assortment of affordable fruits and vegetables essential for healthy diets.

Acknowledgement

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Appendix

Figure 4 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.