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Self-sufficiency in a Small Country? Evidence from an empirical analysis along the supply chain in Puerto Rico

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Abstract

The related literature in self-sufficiency is less informative about the ability of domestic farmers in small countries—which are usually net food importers and more prone to food insecurity—to compete in prices with imports. To increase self-sufficiency in a small country, agricultural goods could substitute imports at different stages of the supply chain. We use Puerto Rico as our case study, where we collected new private price data at different stages along the supply chain that were not previously available. We found that domestic farmers had lower prices than import costs for 30 of 74 agricultural goods. If this economy managed to become self-sufficient in only five of those items, it could have added more than $118 million to its annual gross national product. There were 52 goods that domestic farmers could competitively sell to supermarkets and 22 goods at the restaurant stage. They could also provide 24 imported goods at the family market level. Another alternative was direct marketing, where farmers could compete in almost all the items surveyed. We end up with policy recommendations.

JEL classification: Q11, Q12, Q13, Q18.

Keywords Produce, Self-sufficiency, Agriculture, Food supply chain

Introduction

The global food supply has become more vulnerable due to increasing geopolitical tensions, trade barriers, and environmental crises [53, 54]. While the supply of food under these and other global circumstances has been studied in relatively large countries with abundant land [2, 6, 7, 27, 44, 58], less is known about food security in smaller countries.

Many small countries are net food importers because of structural factors such as land and water scarcity [3, 59] and are more vulnerable to price shocks [41]. An advantage of food trade is that it can raise food security if food is found at lower prices in international markets and when a natural event destroys local production [11]. However, dependency on food imports can also carry disadvantages. If those smaller countries are isolated from bigger countries with large-scale food production, they are more prone to food insecurity in the case of global crises or problems with access to domestic ports [31]. In Puerto Rico, for instance, high food import dependence, "…has contributed to a local food supply that is highly processed, vulnerable to climate change, and misaligned with a cultural heritage rooted in locally grown self-reliance and collective wellbeing" ([32], p. 568). By increasing self-sufficiency (i.e., the territory's ability to meet its food needs through domestic production) [51], residents of small countries can reduce the risk associated with external shocks to food security [11]. However, in

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the literature on self-sufficiency, little attention has been paid to the following question: are domestic food producers in small countries able to compete in price with food imports at any stage of the food supply chain? This is our research question.

Not every small country has the same self-sufficiency ratio [50]. Furthermore, a low self-sufficiency ratio does not imply that farmers are not competitive (i.e. cannot sell at the same or lower price than competitors) for every food item. For example, the Canary Islands have a relatively low self-sufficiency ratio, but domestic farmers appear to be competitive in many unprocessed plant products, some of which are even exported [24]. Similarly, in Scotland, there are low self-sufficiency ratios in poultry and pork, but high ratios in cereals, potatoes, lamb, beef, dairy, and eggs [51]. To the best of our knowledge, there is a lack of empirical analyses that identify the ability of domestic farmers to compete at different stages of the supply chain in small countries. Rather than inferring the ability of domestic farmers to compete, our objective is to directly study their capacity to substitute imports by utilizing private price data at all levels of the food chain in Puerto Rico from 2023. We selected Puerto Rico as our case study because it is an upper–middle-income economy in the Caribbean that shares small country features, such as land scarcity, orientation toward industrialization, and being a net food importer [5, 25, 32].

We identified 74 agricultural goods that can be cultivated domestically, climatically speaking, to determine whether domestic farmers can compete with food imports in terms of price and at what stage along the supply food chan. We found that domestic farmers had lower prices than import costs for the following 30 agricultural goods: sweet pepper, basil, eggplant, summer squash, zucchini, cauliflower, asparagus, guava, green banana, banana, tender bean, ginger, corn, mesclun, green plantain, plantain, radish, green herbs, rocket, watermelon, white mushroom, brown mushroom, portobella mushroom, tamarind, tarragon, cherry tomato, 5 × 6 tomato, grapefruit, purple taro, and benth. At the supermarket level, domestic farmers were competitive (i.e. could sell at the same or lower price than competitors) in 52 out 74 items. Moreover, there were 22 goods that domestic farmers could competitively sell to restaurants and cafeterias. Another alternative would be to substitute imports by online reselling, where farmers could compete with supermarkets in all of the items surveyed, except celery and pumpkin.

If farmers take advantage of this information to engage more in the food supply chain, their income can increase, the dependency on imports can be reduced, and employment may increase. Nandi et al., [38] stated, "Thus, integrating smallholder farmers in organic supply chain not only has a significant influence on domestic market development but also on producer's livelihood" (p. 86). Similarly, Mossie et al., [36] pointed out, "Policies aimed at providing education to farmers and improving access to price information could enhance the ability of households to participate in the fruits value chain and thus improve their food security" (p. 13).

In the following section, we describe the macroeconomic profile of Puerto Rico. In Sect. 3, we present our materials and methods. In Sect. 4, we describe our results and in Sect. 5 we discuss them. Section 6 concludes this study, and we suggest policy recommendations.

The Case of Puerto Rico

Puerto Rico was colonized by the US in 1898 and soon after the economy was fully dollarized [15]. During the first decades of US rule, this economy specialized in sugar cane production. By the mid-20th century, the economic model was changed: Puerto Rico defied its static comparative advantage in agriculture by attracting labor-intensive manufacturers from abroad, especially the US, with federal and domestic tax incentives, a strategy that modernized the economy [57]. However, there were at least two problems with such a model. The first was its fragility; after trade opened in the rest of the world, Puerto Rico's economic growth started to taper off by the mid-1970s. The second problem was its dependency on imports, especially from the US [4]. This dependency included food, as imports represented more than 75% of total food consumption [5, 12].

In many economies that underwent industrialization, the agricultural sector was left behind [43] and Puerto Rico was no exception. In the transition from a low to a high income, the agriculture sector in Puerto Rico was excluded from the economic growth strategy, and in 2021 it represented only 0.6% of the gross domestic product and 1.5% of total employment. In 1950, immediately before the change in the economic growth model of Puerto Rico, the net agricultural income was higher than the net manufacturing income, representing 26% of the total net income of this economy. Even though this net agricultural income increased over time, its share decreased significantly, as shown in Fig. 1. By 2016, it represented 1% of the total net income.

Table 1 shows the data published by the Puerto Rico Institute of Statistics [47]. The quantity harvested in most of these 39 produced items has declined in recent decades. In the fiscal years from 1991 to 2017 (the fiscal year before Hurricane Maria), only the output of onions, banana, cilantro, fresh pigeon pea, lemon, lime, melon, papaya, pickle, pineapple, tomato, and cassava increased. Cassava recovered from a downward pattern and increased in 2016 and 2017. The remaining items (28) had a lower total output in 2017 than in 1991. In the case of avocado, celery, watercress, pork meat, coconut,

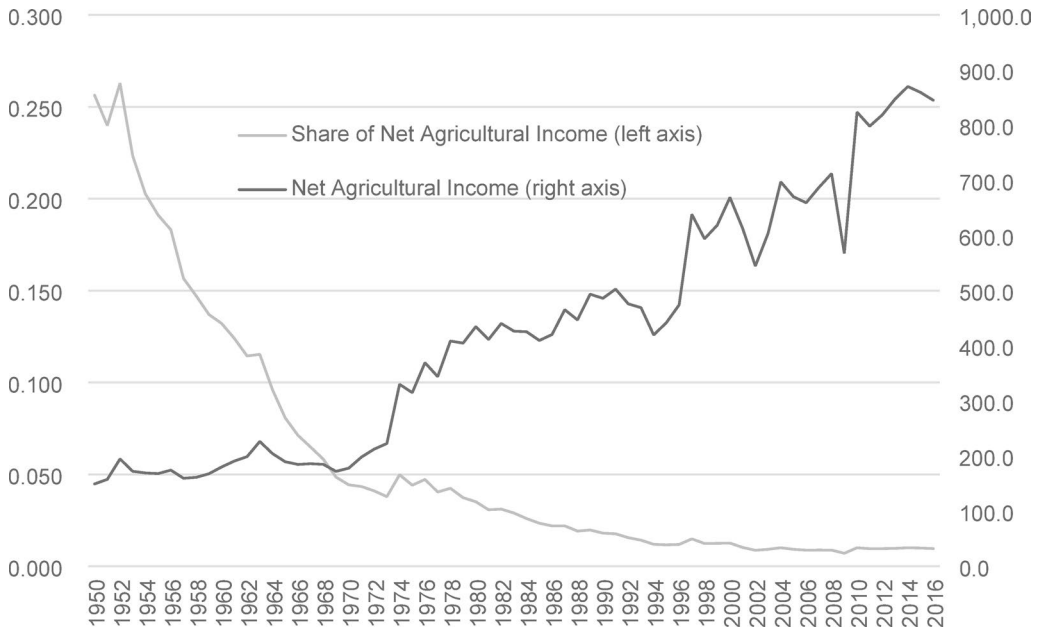

Fig. 1 Total net agricultural income and its share on the total net income, 1950–2016. Note: The figures have been adjusted for inflation using the Gross National Product deflator. The base year is 1954. Source: Author's calculations based on the Puerto Rico Planning Board (2024)

Table 1 Growth rate in domestic physical quantities (quintals) and self-sufficiency ratio of selected agricultural items, 1991–2017

Agricultural items	% Change from 1991 to 2017	Self-sufficiency ratio (%)	Agricultural items	% Change from 1991 to 2017	Self-sufficiency ratio (%)
Avocado	−91.90	9.5	Fresh milk and cream	−39.40	90.0
Celery	−86.30	79.2	Lemon and lime	75.20	4.8
Eggplant	−22.20	100	Taro	−95.30	2.3
Watercress	−90.70	100	Mango	−17.00	100
Coffee	−76.50	18.7	Tender corn	−89.00	1.3
Pumpkin	−76.50	18.7	Melons	187.30	79.3
Pork meat	−82.60	3.4	Other fruits	−88.20	100
Cow meat	−73.50	8.9	Breadfruit	−33.20	100
Onions	66.90	5.0	Papaya	377.10	95.2
Chayote	−39.10	73.5	Pickle	48.90	98.0
Orange	−63.40	39.5	Pepper	−17.10	38.8
Green banana	−42.70	99.9	Pineapple	80.00	66.1
Banana	22.20	100	Plantain	−8.90	99.2
Cilantro and green herbs	216.90	97.2	Spanish lime	−84.3	100
Coconuts	−97.40	17.8	Okra	−24.00	100
Fresh pigeon pea	61.10	70.6	Cabbage	−87.90	5.2
Tender bean	−55.00	2.3	Tomato	26.00	59.5
Fresh vegetables	−15.10	29.5	Grapefruit	−84.60	46.3
Ginger	−33.40	18.0	Taro	−54.70	13.1
Cassava	17.20	29.7			

Self-sufficiency ratio was calculated by dividing the total domestic production net of exports by the sum of total domestic production plus total net imports (imports minus exports)

Author's calculations based on Puerto Rico Institute of Statistics [47]

tender corn, other fruit, Spanish lime, cabbage, and grapefruit, the reduction was larger than 80%. Other produce that saw large decreases were eggplant, coffee, cow meat, chayote, orange, green banana, tender bean, fresh vegetables, ginger, fresh milk and cream, taro, mango, breadfruit, pepper, plantain, okra, and cocoyam.

There was a self-sufficiency ratio (i.e. the total domestic production net of exports divided by the sum of total domestic production plus total net imports) greater than 50% in 18 out of 39 agricultural items whose data were available in 2017. Those were celery, eggplant, watercress, chayote, bananas, cilantro and green herbs, fresh pigeon pea, milk, mango, breadfruit, papaya, pickle, pineapple, plantain, Spanish lime, okra, tomato, and other fruits. The rest had low self-sufficiency. From 1991 to 2019, self-sufficiency averaged 26%. In meat, corn, cabbage, beans, avocado, onions, taro, lemon and lime the self-sufficiency ratio was less than 10%.

The export capacity of the agricultural sector remained small during the period under study. Meat, coffee, pumpkin, coconut, fresh vegetables, milk, mango, and tomato were the only produce that was exported consistently from 1991 to 2019, although in relatively low volumes. According to the Puerto Rico Planning Board, the total export of food in 2022 amounted to $867.7 million.

Self-sufficiency declined after industrialization. From importing approximately 60% of food products in 1929 ([23]; as cited in [15]), in the new century, Puerto Rico was importing approximately 81% of its food [12]. In 2022, food imports represented $4,609.3 million.

Materials and methods

Among the 259 types of produce usually sold in Puerto Rico, we first selected those that have higher consumer demand based on their availability in most food markets, which amounted to 100 items (whole list is shown in Table 5 in Appendix 1). Among those 100 items, we chose those that could be harvested in that country, climatically speaking, resulting in a list of 84 items. We received private data on the cost of imported produce from Hill Brothers and Caribbean Produce, which are the main food distributors in Puerto Rico. These costs are inclusive of transportation costs and tariffs. Tariffs in 2023 were, on average, 4.7% for agricultural goods (WTO, [61]). However, Puerto Rico imported food from the US as well, and there are no tariffs between them due to their colonial relationship.

For the cost of produce bought by restaurants and cafeterias (better known as the "food service" sector) we used the average buying cost of the Cincosentidos Culinary Group (a restaurant in San Juan that buys directly from food importers and distributors). For the price offered to consumers in supermarkets, we averaged the direct prices collected from the vast majority of supermarkets in Puerto Rico, including Wal-Mart, Mr. Special, Hatillo Cash and Carry, Agranel, Ralph's Food Warehouse, Pueblo, Econo, Selectos, Plaza Loiza, and Supermax), and the price offered by farmers is inclusive of transportation costs and was gathered from PRoduce, an online reseller company (i.e., an electronic platform where consumers buy domestic produce). The cost was defined as the amount paid per unit by an entity in the supply chain, and price referred to the amount paid by the final consumers.

We added the prices offered to consumers in family markets—which were determined by the Puerto Rico Department of Agriculture and available on their website—to the database. Family markets are a joint program administered by the Puerto Rico Department of Agriculture and the Department of Family to encourage the public and participants in the Nutritional Assistance Program to buy fresh produce from farmers in their area.

We could not find any data for 10 items, thus the final list consisted in 74 produce. We compare prices for each individual item and use statistical tests to determine if the average price differences are statistically significant for the overall set. Specifically, we utilize paired t-test and the Wilcoxon matched-pairs signed-rank tests. The null hypothesis of the t-test is that $\mu_x = \mu_y$ and the test statistic is distributed as Student's [55] t. The null hypothesis of the Wilcoxon's [60] test is that D = $X_1 - X_2$ = 0, where X is the median of a given distribution. The test statistics is given by,

$$T = \sum_{j=1}^{n} sign\,(d_j)\, rank(/d_j/) \tag{1}$$

where d is the difference for any *j* matched pair of observations and *T*'s distribution follows Fisher's [19] principle of randomization.

Data for the cost of imported produce were an average of the importers' data collected for August 2023; the price in family markets also referenced August 2023; the cost of produce for "food service" was collected in May 2023; the price offered to consumers in supermarkets was collected in March 2023; and the price that domestic farmers received for their produce was collected in July 2023. Since there are some seasonal variations in prices, as a robustness check, we calculated the price differences at each stage of the supply chain under the alternative scenario that the price for the importer, the supermarket, the restaurant, or the family market was 10% lower than the one that we found.

We assume that there are no large differences in quality between domestic and imported produce, as neither has any particular certification. Much of the domestic produce would probably have qualified as organic, but because they are not certified, we could not differentiate their quality from that of foreign corporations that exported to Puerto Rico.

To evaluate whether prices differ by length of perishability, we grouped produce into two categories with the assistance of artificial intelligence. These groups were highly perishable items (H.P.I.) and mid-high perishable items (M.P.I.). H.P.I. in our database is composed of

basil, baby bok choy, chives, cilantro, spinach, soursop, guavas, fresh beans, tender beans, mango, melon (cantaloupe), mesclun, papaya, passionfruit, parsley, dragon fruit, green herbs, rocket, white mushrooms, brown mushrooms, oyster mushrooms, portobella mushrooms, tarragon, cherry tomatoes, and thyme. M.P.I. includes avocado, sweet pepper, bok choy, broccoli, summer squash, zucchini, cauliflower, asparagus, corn, cubanelle pepper, bell pepper, radish, savoy cabbage, watermelon, and 5 × 6 tomato.

Finally, we estimate the macroeconomic effect of substituting the agricultural goods for which domestic farmers had lower prices than the import cost. The total economic effect is composed of the direct effect (i.e. payments to domestic farmers) and the indirect effects (e.g., if domestic farmers had higher income, they would spend more on the domestic economy, generating multiplier effects). Specifically, we compute,

$$macroeconomic\,effect = [M_a\,(QI_i * dp_i)] \quad (2)$$

where QI is the quantity (in pounds) imported of good i (from the Puerto Rico Institute of Statistics, [47]), dp is the domestic farmers' price per unit (from our data), and M_a is 1.6, the agricultural output multiplier from the latest (2017) input-output matrix (Puerto Rico Planning Board, [49]).

Results

Table 2 shows the cost and price differences in the supply chain after averaging the percentage differences for each product in our survey. Prices to final consumers in the supermarkets were, on average, 22.7% higher than those offered to consumers via the online reseller, as shown in Table 2. However, the price offered to consumers in family markets was 18.7% lower than the supermarket price, on average.

Table 3 provides a preliminary overview of the ability of domestic farmers to compete in prices.[1] We directly compared the prices offered by farmers to the costs of different entities in the supply chain. On average, farmers' prices were 37.4% higher than import costs. However, both the t and the Wilcoxon tests show that there were no statistically significant differences in the average and the median of this set. In the case of highly and mid-high perishable items, the price differences between farmers and importers were much lower (14.5% and −4.4%, respectively) but were also not statistically different from zero.

With respect to supermarkets, farmers' prices were generally 32.9% lower, offering the opportunity to sell directly to supermarkets in an effort to compete with imports. The average and median price differences between farmers and supermarkets were statistically significant. The price differences were much higher in the case of highly and mid-high perishable items, with farmers having 41.8% and 54.5% lower prices on average, respectively.

Table 2 Cost and percentage price differences in the supply chain, 2023

Profit margin from import cost to food service cost	22.7%
% difference between food service cost and supermarket price	−33.4%
% difference between family market price and supermarket price	−18.7%
Profit margin from import cost to supermarket price	106%
% difference between online reseller price and supermarket price	23.5%

Profit margin from import cost to food service cost was calculated as: ((food service cost/import cost)−1)*100. The % difference between food service cost and supermarket price equals ((food service cost/supermarket price)−1)*100

Author's calculations based on collected prices

In the case of food services, farmers' prices were generally higher (21.4%) than the costs paid by restaurants and cafeterias for their food, but such a difference was not statistically significant, as reported by the t and Wilcoxon tests. A similar finding applies to for H.P.I. where the average difference was 6.9% but was not statistically significant. However, in M.P.I., local farmers are competitive, offering 26.2% lower prices in general than the cost paid by restaurants, and such a percentage was statistically significant.

In family markets, local farmers had lower prices in general and in M.P.I., and those were statistically significant. However, there was not a statistically significant difference in the average and the median price differences of H.P.I. between farmers and family markets.

It is in direct marketing where local farmers can find the highest profitability to substitute for imports. On average, they had 51.8% lower prices than the prices offered by direct marketing. Such a percentage was even higher for H.P.I. (58%) and M.P.I. (60.4%).

As shown in Table 6 in Appendix 1, domestic farmers were able to compete directly with the import prices for the following produce: sweet pepper, basil, eggplant, summer squash, zucchini, cauliflower, asparagus, guava, green banana, banana, tender bean, ginger, corn, mesclun, green plantain, plantain, radish, green herbs, rocket, watermelon, white mushroom, brown mushroom, portobella mushroom, tamarind, tarragon, cherry tomato, 5 × 6 tomato, grapefruit, purple taro, and benth. In other words, at the import level, domestic farmers had lower prices for 30 of 74 items in our sample. However, the price advantages in ginger, radish, 5 × 6 tomato, purple taro, and benth disappear under the alternative

[1] It would have been ideal to weigh these averages by their shares of the total value of agricultural imports, but there is no import data for most of the produce, except for the 39 items shown in Table 1 in the second section.

Table 3 Percentage differences between farmers' prices and cost in the supply chain, 2023

	% difference	*P*-value t test (H0: mean of the differences is zero)	*P*-value Wilcoxon Signed-Rank test (H0: median of the differences is zero)
General, between farmers' price and import cost	37.4%	0.1004	0.3019
H.P.I., between farmers' price and import cost	14.5%	0.4524	1.00
M.P.I., between farmers' price and import cost	−4.4%	0.5614	0.3018
General, between farmers' price and supermarket prices	−32.9%	0.0000	0.0000
H.P.I., between farmers' price and supermarket prices	−41.8%	0.0001	0.0072
M.P.I., between farmers' price and supermarket prices	−54.5%	0.0001	0.0001
General, between farmers' price and food service cost	21.4%	0.7606	1.00
H.P.I., between farmers' price and food service cost	6.9%	1.00	1.00
M.P.I., between farmers' price and food service cost	−26.2%	0.0026	0.0352
General, between farmers' price and family market price	−10.4%	0.0129	0.0652
H.P.I., between farmers' price and family market prices	−8.6%	0.1763	0.7744
M.P.I., between farmers' price and family market prices	−42.3%	0.0234	0.0703
General, between farmers' price and direct market price	−51.8%	0.000	0.000
H.P.I., between farmers' price and direct market prices	−58.0%	0.000	0.000
M.P.I., between farmers' price and direct market prices	−60.4%	0.002	0.002

H.P.I. stands for highly perishable items and M.P.I. stands for mid-high perishable items. We use paired t tests with the alternative hypothesis that the mean difference is not equal to zero. For the Wilcoxon matched-pairs signed-rank test, we show the exact p-value, which is based on the actual randomization distribution of the test statistics

Author's calculations based on collected prices

scenario in which the import price was 10% lower than the surveyed.

At the supermarket level, domestic farmers were competitive in all the produce in which they are able to compete at the import level. In addition, they can also sell to supermarkets the following produce at lower prices: avocado, purple garlic, garlic leek, broccoli, yellow onion, white onion, red onion, orange, cilantro, pomegranate, cabbage, taro, mango, melon cantaloupe, yam, parsley, bell pepper, savoy cabbage, romero, dragon fruit, purple cabbage, and carrot. All those price differences hold under the alternative scenario of 10% lower cost to supermarkets. Note that we did not find data for supermarkets for all produce, but if one assumes that the 30 items that can be substituted at the import level can also be substituted at the supermarket level, then domestic farmers are competitive at the supermarket level in 52 out of 74 items.

At the food service level, domestic producers can compete in 22 items: avocado, sweet pepper, eggplant, bok choy, broccoli, summer squash, zucchini, cilantro, cauliflower, asparagus, cabbage, corn, melon cantaloupe, cubanelle pepper, green plantain, radish, purple cabbage, watermelon, white mushroom, brown mushroom, grapefruit, and carrot. However, the price advantages in purple cabbage, asparagus, and bok choy disappear under the alternative scenario in which the food service cost was 10% lower than the surveyed cost.

Domestic farmers could substitute imports at the family market level in avocado, sweet pepper, basil, white sweet potato, eggplant, cilantro, bananas, green bananas, fresh beans in grain, ginger, cabbage, corn, mango, mesclun, pickle, cubanelle pepper, bell pepper, green plantain, green herbs, rocket, watermelon, 5 × 6 tomato, yellow taro, and purple taro. However, the price differences in purple and yellow taro do not hold in the alternative scenario. Domestic farmers could also compete in direct marketing for almost every item, except celery (domestic root vegetable) and pumpkin. The only price difference that disappears in the alternative scenario was in oranges.

Using the available import data from the Puerto Rico Institute of Statistics [47], we found that Puerto Rico was close to self-sufficiency with eggplant, green banana and banana, pickle, plantain, and green herbs, as shown in the second section. However, in the case of corn, pepper, tomato, grapefruit, and taro, there was a relatively low level of production. In 2017, 122 quintals of corn were produced domestically, representing almost 0% in self-sufficiency; 70,432 quintals of domestic pepper equaled 19.8% of the total pepper consumption; 396,896 quintals of tomato were domestically harvested, accounting for almost half of the total tomatoes consumed; 9,432 quintals of grapefruit were grown domestically, equating to 14.8% of the total grapefruit consumption; and 22,313 quintals of domestic taro signified 15.8% of the overall consumption. These data are shown in Table 4.

There were no data on total imports for the 30 items, in which domestic farmers were competitive compared to import costs. Thus, Table 5 shows only the five items for which domestic farmers were competitive but that were being heavily imported. The substitution of those imports would have represented a direct economic effect

of $73.6 million, enhanced by indirect economic effects. The total direct and indirect effects of this potential import substitution could have represented $118 million in economic activity in Puerto Rico in 2023. Note that this economic activity is not for a single year and would represent recurrent economic activity in subsequent years.

Discussion

We compared the domestic produce price with the prices paid at each stage of the supply chain. In doing so, we identified that domestic farmers were able to substitute some imports better than others at different stages of the supply chain. These results are similar to those of Godenau et al., [24] and Rathnayaka et al., [51], who found that farmers in the Canary Islands and Scotland, respectively, were able to compete in many produce items.

The 30 items of produce that can be substituted at the import level share the characteristic of high-priced perishable crops, needing road connectivity, careful storage, and refrigerated transport, which can increase the relative cost of imports. In fact, we found that domestic farmers are providing lower prices for goods with mid-to-high perishability at all stages in the supply chain. Perhaps domestic farmers are taking advantage of the infrastructure to reduce costs associated with preserving these perishable items relative to the constraints faced by importers in efficiently handling perishable items.

There were other produce types that were not competitive at the import level but were at the food service level. Food service is a relatively large subsector in which farmers sell significant amounts of produce. In the 2017 economic census in Puerto Rico, the total sales to restaurants equaled $3.023 billion [8].

If a type of produce was not competitive at the food service level, domestic farmers could substitute imports at the family market level. Conner et al., [13] argued that when farmers distributed their production at family markets, their profitability and long-term viability increased. Another alternative for farmers was to substitute imports using an online reseller, where they could compete with supermarkets to target final consumers. This is actually the most profitable niche for domestic farmers.

On average, the import cost of produce is half that of the supermarket price for consumers. Thus, to substitute imports on a competitive basis, the farmers' price for a given domestic product cannot be the same as the price in the supermarket. Another alternative for domestic farmers, which may be more profitable in some cases, is to sell their produce at family markets.

Even though in other countries transporting food internally is more costly than transporting it internationally [34, 35], in Puerto Rico and in many other high-income economies, this may not always be the case. First, unlike many mid- and low-income countries, roads are paved with concrete in Puerto Rico, and most farms can be reached within a couple of hours and are closer than the single port (in the capital city) that is used to trade internationally. Second, anything that is transported between Puerto Rico and the US is subject to the 1920 Jones Act, which requires that cargo between US ports (including Puerto Rico ports) can only be made by vessels owned, crewed, registered, and built in the US, which were the most expensive in the world. The US is Puerto Rico's number one trading partner, supplying 57% of the country's total imports. There are no official statistics for how much food for final consumption is imported from the US, but based on data from the Puerto Rico Planning Board, we estimate that roughly 56% of the $4.8 billion of food imported in 2023 in Puerto Rico comes from the US.

The 1920 Jones Act increases import costs [26]. A report found that the 1920 Jones Act on average raises food prices in Puerto Rico by 7.2% [1]. If one combines the 7.2% impact of the 1920 Jones Act with the 4.7% tariff rate (as mentioned in the third section), one can state that those barriers to trade amount to an 11.9% higher import cost. Thus, the domestic ability to compete in seven products (cauliflower, ginger, radish, cherry tomato, 5 × 6 tomatoes, purple taro, and benth) may respond to barriers to trade.

Even though those barriers to trade may help some domestic producers compete against imports, they may harm others. This is because, in agriculture, many intermediate inputs (e.g., fertilizers, seeds, and grains for feeding animals) are also imported [56]. Furthermore, the 1920 Jones Act could also isolate Puerto Rico from international logistics, reducing domestic producers' ability to export and to buy intermediate inputs at competitive prices through international trade.

Table 4 Self-sufficiency in competitive produce and its economic potential

Items	Direct economic impact with 100% of import substitution in 2023 ($)	Self-sufficiency ratio in 2019 (%)
Corn	1,129,920	0
Pepper	5,988,600	19.8
Tomato	36,256,080	54.1
Grapefruit	1,235,316	14.8
Taro	29,026,032	15.8
Total direct effect	73,635,948	
Total direct + indirect economic effects	117,817,517	

Direct effects were calculated by multiplying the quantity (in pounds) imported of good i by the domestic farmers' price per unit (from our data). The direct effect was multiplied by 1.6, the agricultural output multiplier from the input-output matrix

Author's calculations based on Puerto Rico Institute of Statistics [47], Puerto Rico Planning Board [49], and collected prices

Another policy that may aid self-sufficiency in Puerto Rico is the US phytosanitary measures imposed on Puerto Rico, as a US colony, that reduce food imports from the rest of the world and allow more import substitution. However, Peterson et al., [45] found that the impact of those restrictions on trade declined once foreign competitors accumulated experience.

Even though a small economy faces land and climatic constraints to achieving high self-sufficiency [41, 59], among the products that can be grown in Puerto Rico, there remains low domestic production. This is not due to a lack of ability of domestic farmers to compete in prices because they can generally compete with most of the imports in our sample at the final consumer level, although not at other levels in the supply chain.

Given perfect information, buyers at different stages of the supply chain would have preferred to buy more from local producers. However, agrifood markets in many countries are far from perfect and asymmetric information on pricing and transaction costs may arise [35, 38]. Thus, it is likely that neither the suppliers nor the buyers know at what price one is buying and the other is producing. In Puerto Rico, there is no official dataset with current agricultural prices, but countries such as the Dominican Republic publish weekly data on agricultural prices at the wholesale and retail level (MERCADOM, [33]).

Besides asymmetric information, there are other reasons for low self-sufficiency despite the ability of domestic farmers to compete in terms of price. First, in the case of supermarkets, domestic farmers may avoid selling to them because of their "stringent" supply terms, such as high-quality standards, strict delivery methods, and recall of unsold products [16]. Reardon and Hopkins, [52] also point out "behavioral tensions" between supermarkets and domestic suppliers, such as late payments, promotion fees, and package design, among others, which can discourage supermarkets from selling more food from domestic production. These transaction costs increase the cost of establishing new supply chains. Second, the related literature points to the low productive capabilities of small farmers who are focused on regional markets than leading farmers [37]. A third factor can be the family traditions that guide farmers' decisions [21] but limit the ability of farmers to produce a new product. Fourth, the "produce first, then look for the market" approach of traditional farmers [38] may also restrict their integration into profitable niches in supply chain integration.

If farmers substitute more imports, consumers will also benefit. If there is an articulated effort to substitute those imports discussed, the cost of food in Puerto Rico will be reduced. Nedumaran et al., [40] stated, "Integrating smallholder farmers in the supply chain leads not only to higher prices for producers but also lower prices for consumers" (p. 320). According to the Cost of Living Index published by the Council for Community and Economic Research [14], among 304 metropolitan areas in the US, Puerto Rico ranked as the 19th most expensive for supermarket items.

Increasing agriculture is also related to regional growth in rural areas [29]. Domestic farmers can also take advantage of the fact that domestic consumers prefer domestic food because of quality, macroeconomic, and sustainability issues [10, 39, 42]. However, the benefits of producing more food go beyond the multiplier effect of import substitution. Higher self-sufficiency could help islands that are prone to natural events—such as Puerto Rico—during an emergency [32]. In addition, increasing food self-sufficiency can also reduce price volatility, which is observed when there is a dependency on food imports [30] and in small economies in the Caribbean [20]. In fact, the food price index in Puerto Rico had a Pearson correlation of 0.99 with the food price index in the US (the main trade partner) and increased when international prices surged, as shown in Fig. 2. Because imports represented more than 75% of total food consumption [5, 12], it would appear that there is relatively high exposure to global shocks in prices, but more research is needed on this aspect.

One could argue that our findings were driven by the increase in international prices, which could close the gap between domestic and border prices in food-importing countries [2]. However, according to the real Food and Agriculture Organization (FAO) food index of international prices, the year 2023 was not an outlier, and similar prices were observed in subsequent years in the global market and in the US, as shown in Fig. 2.

Conclusions and Policy Recommendations

Similarly to many other economies that transition to an upper–middle-income status, agricultural output and employment decreased during the industrialization of Puerto Rico and in its aftermath [9]. In the fiscal year 2017, a year before Hurricane Maria, Puerto Rico was self-sufficient only in relation to certain produce. However, domestic farmers in this type of economy can still be competitive in a number of agricultural goods. Such competitiveness should be evaluated not only at the import level but at the restaurant and final consumer stages.

We obtained access to unique data on the costs and prices of produce that allowed us to evaluate the feasibility of substituting imports at different stages of the supply chain. There were 30 agricultural goods that could be replaced at the import level, 52 at the supermarket level, 22 goods at the restaurant stage, and almost all by direct online reselling. Simply by substituting imports with five items that domestic farmers offered at lower prices, more than $117 million could have been generated in new

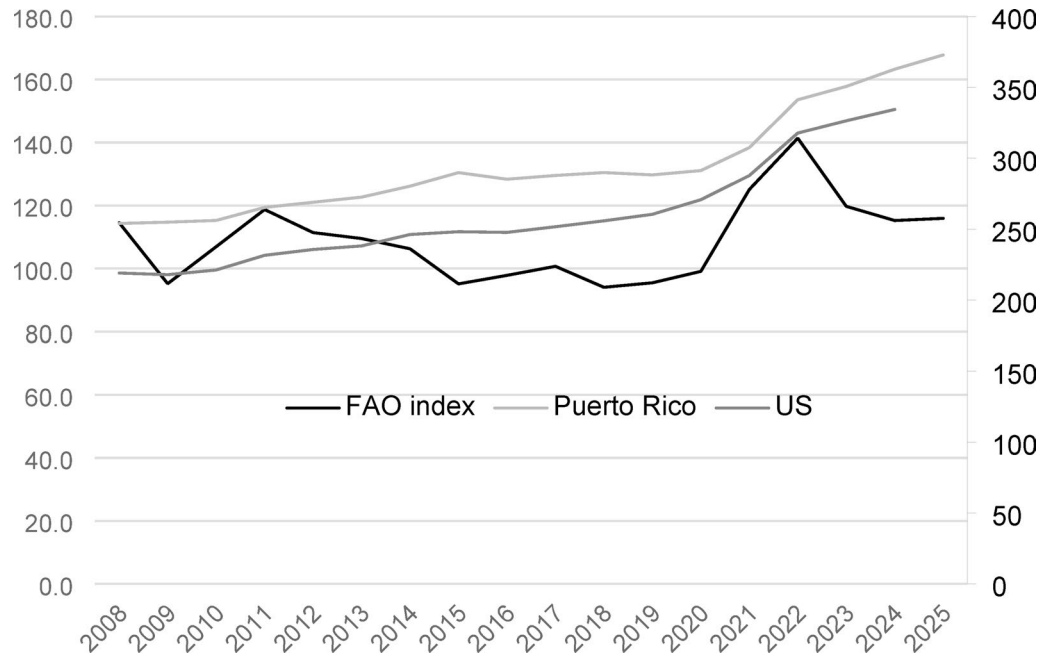

Fig. 2 Food price index in FAO, US, and Puerto Rico, 2008–2025. Note: The US food price index is the average for all urban consumers. The Puerto Rico food price index includes food and beverages. Source: Author's calculations based on FAO [17], Federal Reserve Bank of St. Louis [18], Puerto Rico Department of Labor [46]

economic activity in Puerto Rico in 2023. This amount could be even larger if we had data on most items where self-sufficiency could be achieved. While such potential agricultural output may not be substantial relative to the size of the economy (Gross National Product equaled $82 billion in 2023) (Puerto Rico Institute of Statistics, [48]), it is not intended to substitute for but to complement other growth strategies for this economy.

Increasing self-sufficiency in food items in which local producers are competitive will not only improve outcomes for the economy at large and access to affordable food. Self-sufficiency may also increase future food supply and resilience to future external shocks for consumers, and preservation of assets and livelihoods for rural producers [22]. Thus, we recommend that an articulated project be implemented to increase self-sufficiency in similar economies. First, mass dissemination of weekly price data at the wholesale and retail levels must be undertaken by the government so that both farmers and buyers at every stage of the supply chain can achieve near-perfect information. It would be in their best interests to obtain lower prices and be more competitive. Second, the local government must help domestic farmers access land and inputs. Third, organic agriculture can provide business opportunities for domestic farmers because of its higher profit margins and demand in high-income countries such as Puerto Rico [28]. These organic items can also be exported to developing countries, where there is a preference for organic food currently produced in upper-income countries [42]. Fourth, the private sector should evaluate how semi-processing and value addition in other food products can increase self-sufficiency and link local farmers to the food industry. Caraballo-Cueto, [8] finds that supermarkets in Puerto Rico buy relatively high amounts of grains, seasoning, spices, vinegar, soups, and flour items from local food industries.

Limitations of our study are that it was too costly to find private price data for many years that would allow the estimation of period averages, that our sample may not be representative of other countries with different food preferences, and that we do not know the specific reason for the low self-sufficiency. Does relatively low self-sufficiency respond to supply-side considerations or demand-side factors? We have presented these results at conferences to farmers and supermarkets buyers, and they both complained about the lack of interest from the other party in doing business with them. Thus, future studies can interview buyers more in-depth buyers in retailers and food services to find what leads them to avoid buying more domestic produce, and interview domestic farmers to incorporate their views on why self-sufficiency is relatively low despite their revealed competitiveness in some items. However, such important qualitative analysis deserves a whole new research beyond the scope of this article.

Appendix 1.

See Tables 5 and 6.

Table 5 List of produce and categorization in terms of consumer demand

Does it have a high demand?	Item
No	Abiu
No	Swiss chard
Yes	Acerola cherry
No	"Black Beauty" avocado
No	Ávila avocado
Yes	Avocado
No	Pollock avocado
No	Wilson Popenoe avocado
No	Caballero pepper
Yes	Sweet pepper
No	Habanero pepper
Yes	Spanish purple garlic
Yes	Leek
Yes	Basil
No	Thai basil
No	Tulsi basil/Holy basil
No	Sugar apple
Yes	Celery root/Celeriac (local root vegetable)
No	Celery root/Celeriac
No	Ausubo fruit
Yes	Baby bok choy
Yes	Baby kale mix
Yes	Sweet potato
No	Canol sweet potato
Yes	Eggplant
No	Barbarella eggplant
No	White eggplant
No	Chinese eggplant
No	Gretel eggplant
No	Mini eggplant
No	Orient eggplant
No	Watercress
Yes	Bok choy
Yes	Broccoli
No	Bamboo shoots
No	Cacao
No	Star apple
Yes	Zucchini (summer squash)
Yes	Green zucchini
Yes	Pumpkin/Squash
No	Pattypan squash
No	Canistel/Eggfruit
No	Starfruit/Carambola
Yes	Yellow onion
No	Shallot
Yes	White onion
Yes	Red onion
Yes	Scallions/Green onions
No	Celery
No	Chinese celery
No	Chayote
No	Potato chayote
Yes	Orange

Table 5 (continued)

Does it have a high demand?	Item
Yes	Mandarin orange
No	Chironja (orange-grapefruit hybrid)
Yes	Cilantro (culantro)
No	Peeled coconut
No	Dried coconut
Yes	Cauliflower
No	Collard greens
No	Heart (of palm or similar)
No	Cucamelon "Mexican melon cucumber"
No	Turmeric
No	Edamame
Yes	Asparagus
Yes	Spinach
No	Komatsuna spinach
No	Asian spinach
Yes	Vanilla extract
No	Squash blossom
No	Hibiscus flower
No	Galangal
No	Garcinia
No	Garlic chives
No	Alfalfa sprouts
No	Bean sprouts
No	Broccoli sprouts
No	Clover sprouts
No	Rainbow mix sprouts
No	Ghost pepper
No	Golden oyster (mushroom)
Yes	Pomegranate
No	Gooseberry/Currant
No	Ice cream bean/Guama
Yes	Soursop
Yes	Guavas
Yes	Ripe plantain
No	Mafafo banana
No	Apple banana
No	Purple banana
No	Baby banana
Yes	Green plantain
No	Creole pinto beans
Yes	Pink beans
Yes	Green beans/String beans
No	Fennel
No	Fennel leaf
No	Chayote leaf
No	Curry leaf
No	Hibiscus leaf
No	Mustard greens
No	Plantain leaf/Banana leaf
No	Sage leaf
No	Nettle leaves
No	Pennyroyal leaves
Yes	Jackfruit

Table 5 (continued)

Does it have a high demand?	Item
No	Genip
Yes	Ginger
No	Hog plum/Jobo
No	Kabocha squash
Yes	Kale (curly kale)
No	Russian kale
No	Tuscan kale/Lacinato kale
No	Ketembilla/Ceylon gooseberry
Yes	Bay leaf
Yes	Local lettuce
No	Lerenes/Guinea arrowroot
No	Cabro lemon
No	Sweet lemon
No	Meyer lemon
Yes	Lime (green lemon)
No	Spanish lime/Mamoncillo
No	Longan
No	Lulo/Naranjilla
No	Lychee
No	Strawberry tree fruit
Yes	Corn
Yes	Malanga/Taro
Yes	White malanga
No	Mamey sapote
No	Mamey sapote
No	Edward mango
No	Francisque mango
No	Hadden mango
No	Irwin mango
Yes	Keitt mango
No	Kent mango
No	Nam dok mai mango
No	Namdocmai mango
Yes	Palmer mango
No	Parvin mango
No	Pascual mango
No	Pineapple mango
No	Pope mango
No	Sensation mango
No	Tommy Atkins mango
No	Maricao berry
Yes	Cantaloupe melon
No	Kiwano melon/Horned melon
Yes	Mesclun/Mixed greens
No	Mini sweet peppers
Yes	Florida yam
Yes	Guinea yam
Yes	Habanero yam
No	Purple yam
No	Sapodilla
No	Loquat/Japanese medlar
No	Okra (gumbo)
No	Wild oregano

Table 5 (continued)

Does it have a high demand?	Item
No	Greek oregano
No	Nettle
No	Pak choi/Bok choy
Yes	Breadfruit
No	Cut and cleaned breadfruit
Yes	Baby white potatoes
Yes	Baby red potatoes
Yes	Papaya
Yes	Passion fruit
Yes	Pickle/Gherkin
No	Lemon cucumber
No	Pickling cucumber
No	Salt and pepper cucumber
Yes	Parsley
No	Biquiño pepper
No	Cayenne pepper
Yes	Cubanelle pepper
No	Padrón pepper (roulette)
No	Habanero pepper
No	Italian pepper
No	Jalapeño pepper
Yes	Bell pepper
No	Poblano pepper
No	Serrano pepper
No	Shishito pepper
No	Thai pepper
No	Thai pepper
Yes	Pineapple
Yes	Dragon fruit/Pitaya
No	Surinam cherry/Pitanga
Yes	Ripe plantain
Yes	Green plantain
No	Rose apple
No	Pulasan
No	Purple garlic
Yes	Spanish lime/Quenepa
No	Okra (gumbo)
No	"Cherry Belle" radish
No	Bacchus radish
No	White radish (white icicle)
No	Wild radish
No	Daikon radish
No	French radish
Yes	Red radish
No	Watermelon radish
No	Rambutan
No	Yellow rambutan
Yes	Culantro/Recao
Yes	Beet/Beetroot
No	Danish cabbage
Yes	Purple cabbage
No	Napa cabbage
Yes	Savoy cabbage

Table 5 (continued)

Does it have a high demand?	Item
Yes	Rosemary
Yes	Arugula/Rocket
No	Aloe vera
No	Sage
Yes	Watermelon
No	Santol
No	Chupa sapote
No	Black sapote
Yes	White mushrooms
Yes	Sliced white mushrooms
Yes	Brown mushrooms
Yes	Oyster mushrooms
Yes	Portobella mushrooms
No	Shallots
No	Spaghetti squash
Yes	Tamarind
No	Tangelo
Yes	Tarragon
No	Tokyo bekana
Yes	Cherry tomato
No	Clementine tomato
No	Indigo Apple tomato
No	Plum tomato
No	San Marzano tomato
Yes	Grape tomato
Yes	5 × 6 tomatoes
Yes	Thyme
Yes	Grapefruit
No	Vanilla bean/pod
No	Purslane
Yes	Yellow yautía/Malanga
Yes	Purple yautía
Yes	Spearmint/Mint
No	Yu choy sum
Yes	Yucca/Cassava
Yes	Carrot
Yes	Organic carrot
Yes	Ricotta
Yes	Mozzarella
Yes	Pork ham
Yes	Turkey ham
Yes	Chicken ham
Yes	Tomato sauce
Yes	Tomato paste
Yes	Broth (chicken broth)
Yes	Broth (beef broth)
Yes	Broth (vegetable broth)
No	Zocato

Table 6 Cost and percentage price differences for each item in the supply chain, 2023

Item	% difference between farmer and import cost	Scenario with 10% lower import cost	% difference between farmer and supermarket prices	Scenario with 10% lower supermarket prices	% difference between farmer and food service cost	Scenario with 10% lower food service cost	% difference between farmer and family market price	Scenario with 10% lower family market prices	% difference between farmer and direct market price	Scenario with 10% lower direct market prices
Avocado	6%	18%	−64%	−60%	−37%	−30%	−50%	−44%	−54%	−48%
Sweet pepper	−77%	−74%	−77%	−75%	−81%	−79%	−78%	−75%	−85%	−83%
Purple garlic (Spain type)	100%	122%	−36%	−29%	73%	92%				
Garlic leek	67%	85%	−16%	−6%	34%	49%				
Basil	−47%	−41%	−92%	−91%			−53%	−48%	−73%	−70%
Celery	174%	205%	20%	33%			18%	32%	26%	40%
Baby bok choy	209%	243%								
White sweet potato	88%	109%	4%	16%	91%	112%	−19%	−10%	−63%	−58%
Eggplant	−14%	−5%	−29%	−21%	−18%	−8%	−32%	−24%	−50%	−44%
Bok choy	46%	62%			−6%	4%			−76%	−73%
Broccoli	43%	59%	−46%	−40%	−28%	−20%			−48%	−42%
Summer squash	−23%	−15%	−55%	−50%	−47%	−41%			−58%	−53%
Zucchini	−20%	−11%	−54%	−49%	−44%	−38%			−57%	−52%
Pumpkin	168%	198%	33%	47%	162%	191%	36%	51%	40%	55%
Item	% difference between farmer and import cost	Scenario with 10% lower import cost	% difference between farmer and supermarket prices	Scenario with 10% lower supermarket prices	% difference between farmer and food service cost	Scenario with 10% lower food service cost	% difference between farmer and family market price	Scenario with 10% lower family market prices	% difference between farmer and direct market price	Scenario with 10% lower direct market prices
Yellow onion	83%	104%	−19%	−10%	92%	113%	61%	79%	−51%	−45%
White onion	79%	99%	−55%	−51%						
Red onion	114%	137%	−23%	−15%	190%	223%				
Chives	127%	152%	21%	34%					−32%	−24%
Orange	71%	90%	−31%	−23%					−4%	7%
Mandarin orange	62%	80%	28%	42%						
Cilantro	26%	40%	−67%	−63%	−13%	−4%	−35%	−27%	−51%	−46%
Cauliflower	−11%	−1%	−54%	−49%	−47%	−41%			−49%	−43%
Asparagus	−26%	−18%	−50%	−44%	−2%	9%				
Spinach	77%	97%	25%	39%	55%	72%				
Pomegranate	29%	43%	−50%	−44%						
Soursop							67%	86%		
Guavas	−50%	−45%	−61%	−56%			34%	49%	−59%	−54%
Bananas	−54%	−49%	−59%	−55%			−45%	−39%	−59%	−55%
Green banana	−69%	−66%	−70%	−67%			−63%	−59%		
Fresh bean							−17%	−8%		

Table 6 (continued)

Item	% difference between farmer and import cost	Scenario with 10% lower import cost	% difference between farmer and supermarket prices	Scenario with 10% lower supermarket prices	% difference between farmer and food service cost	Scenario with 10% lower food service cost	% difference between farmer and family market price	Scenario with 10% lower family market prices	% difference between farmer and direct market price	Scenario with 10% lower direct market prices
Tender bean	−17%	−8%	−38%	−32%					−64%	−60%
Jackfruit	166%	196%								
Item	% difference between farmer and import cost	Scenario with 10% lower import cost	% difference between farmer and supermarket prices	Scenario with 10% lower supermarket prices	% difference between farmer and food service cost	Scenario with 10% lower food service cost	% difference between farmer and family market price	Scenario with 10% lower family market prices	% difference between farmer and direct market price	Scenario with 10% lower direct market prices
Ginger	−2%	9%	−50%	−44%			−43%	−37%		
Kale	169%	199%	33%	48%	40%	56%			−35%	−28%
Cabbage	45%	61%	−45%	−39%	−17%	−7%	−51%	−45%	−68%	−65%
Lime	69%	87%	18%	31%	32%	46%	0%	11%	−27%	−19%
Corn	−41%	−34%	−59%	−55%	−34%	−26%	−73%	−69%		
Taro	73%	92%	−21%	−12%	46%	62%	40%	56%	−65%	−61%
Mango	50%	67%	−27%	−19%	7%	19%	−26%	−17%		
Melon cantaloupe	12%	24%	−59%	−55%	−18%	−9%	70%	89%	−59%	−55%
Mesclun	−29%	−21%					−37%	−30%	−61%	−56%
Yam (florido)	77%	96%	−40%	−33%	89%	110%				
Yam (guinea)	78%	98%								
Yam (habanero)	186%	218%								
Red baby potatoes	203%	237%								
Papaya	64%	82%	73%	92%	58%	75%	1%	12%		
Passionfruit							17%	30%	−53%	−48%
Pickle	0%	11%	−58%	−54%			−47%	−41%		
Parsley	29%	43%	−31%	−23%	32%	46%			−48%	−43%
Item	% difference between farmer and import cost	Scenario with 10% lower import cost	% difference between farmer and supermarket prices	Scenario with 10% lower supermarket prices	% difference between farmer and food service cost	Scenario with 10% lower food service cost	% difference between farmer and family market price	Scenario with 10% lower family market prices	% difference between farmer and direct market price	Scenario with 10% lower direct market prices
Cubanelle pepper	−23%	−15%	−54%	−49%	−26%	−18%	−59%	−55%	−59%	−54%
Bell pepper	58%	75%	−36%	−29%	11%	23%	−4%	7%		
Pineapple	292%	336%	46%	62%	233%	270%	143%	170%		
Dragon fruit			−37%	−29%					−29%	−21%
Plantain	−70%	−67%	−76%	−73%						
Green plantain	−57%	−52%	−64%	−60%	−71%	−68%	−50%	−44%	−75%	−72%
Spanish limes	−29%	−21%								

Table 6 (continued)

Item	% difference between farmer and import cost	Scenario with 10% lower import cost	% difference between farmer and supermarket prices	Scenario with 10% lower supermarket prices	% difference between farmer and food service cost	Scenario with 10% lower food service cost	% difference between farmer and family market price	Scenario with 10% lower family market prices	% difference between farmer and direct market price	Scenario with 10% lower direct market prices
Radish	−2%	9%	−54%	−49%	−11%	−1%			−54%	−49%
Green herbs	−90%	−89%	−90%	−89%			−81%	−79%	−89%	−87%
Beet	216%	251%	209%	244%	226%	262%				
Purple cabbage	25%	39%	−15%	−5%	−4%	7%				
Savoy cabbage	64%	82%	−31%	−23%	14%	27%	36%	51%	−66%	−62%
Romero	3%	15%	−54%	−49%					−52%	−47%
Rocket	−18%	−8%	−62%	−58%			−44%	−37%	−50%	−44%
Watermelon	−57%	−52%	−79%	−77%	−63%	−59%	−80%	−78%		
White mushroom	−38%	−31%	−71%	−68%	−47%	−42%			−75%	−73%
Item	% difference between farmer and import cost	Scenario with 10% lower import cost	% difference between farmer and supermarket prices	Scenario with 10% lower supermarket prices	% difference between farmer and food service cost	Scenario with 10% lower food service cost	% difference between farmer and family market price	Scenario with 10% lower family market prices	% difference between farmer and direct market price	Scenario with 10% lower direct market prices
Brown mushroom	−30%	−22%	−74%	−71%	−46%	−40%			−74%	−71%
Oyster mushroom	100%	122%							−44%	−38%
Portobella mushroom	−30%	−22%	−78%	−76%					−75%	−72%
Tamarind	−59%	−54%	−74%	−71%			105%	128%		
Tarragon	−31%	−23%								
Cherry tomato	−10%	0%	−42%	−35%	36%	51%			−51%	−45%
5 × 6 tomato	−4%	7%	−48%	−43%	9%	21%	−32%	−24%		
Thyme	0%	12%								
Grapefruit	−28%	−21%	−60%	−56%	−57%	−52%				
Yellow taro	95%	117%					−2%	9%		
Purple taro	−4%	7%	−35%	−27%	10%	22%	−6%	4%		
Benth	−3%	8%							−51%	−45%
Cassava	67%	85%	41%	57%	35%	50%	0%	11%		
Carrot	7%	18%	−48%	−42%	−19%	−10%				
Organic carrot	188%	220%			126%	151%				

Only produce that we found price data for is shown. Thus, ten items from the original list were removed from this table

Author's calculations based on collected prices

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There is a single author in this manuscript.

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Declarations

Competing interests
The authors declare no competing interests.

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