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Technology, Policy, and Market Adaptation Mechanisms for Sustainable Fresh Produce Industry: The Case of Tomato Production in Florida, USA

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Abstract: Tomato (*Solanum lycopersicum* L.) is an important vegetable crop in Florida, a state located in the south-eastern region of the United States. The state is the second largest producer of tomatoes in the country and contributes to almost 90% of the domestic winter tomato supplies. However, tomato farmers in Florida have come under increasing pressure due to climate changes, foreign imports, and rising production costs. The purpose of this paper is to analyze whether Florida tomato growers will continue to sustain their production given the seasonal and geographic production advantage, yet against various internal and external threats emerging throughout the fresh produce supply chain. We developed our study on a multi-disciplinary conceptual model of network (supply chain) relationship and primary and secondary data gathered from various stakeholders and the literature. We found that Florida farmers have done remarkably well by adapting to warming temperatures and changing consumer expectations about environmental sustainability and responsible labor practices. However, foreign competition, labor shortage, the rising costs of inputs, extreme weather events (hurricanes), and pests and diseases due to humid climate continue to affect the sustainability of the Florida tomato production. Our paper suggests various farm-, market-, and institution-level adaptation mechanisms for preventing the regional production advantage of the Florida tomato industry from eroding. Newer immigration laws are necessary for easing the labor situation. In order to have a level playing field with respect to the use of protected agriculture technology such as in Mexico and Canada, U.S. farmers in general and Florida farmers in particular need government support. Florida farmers need to diversify their fresh produce market strategies, finding new product streams. There is also a need for reforming the product certification landscape, which some growers find cumbersome and cost prohibitive. Growers may gain from being better able to convey to consumers the information regarding their effort put into environmental sustainability, workers welfare, and safe food.

Keywords: tomato; Florida; environmental sustainability; fair food; produce supply chain

Citation: Chanda, S.; Bhat, M.; Shetty, K.G.; Jayachandran, K. Technology, Policy, and Market Adaptation Mechanisms for Sustainable Fresh Produce Industry: The Case of Tomato Production in Florida, USA. *Sustainability* **2021**, *13*, 5933. https://doi.org/10.3390/su13115933

Academic Editor: Boon Lee

Received: 17 April 2021
Accepted: 13 May 2021
Published: 25 May 2021

1. Introduction

The production and marketing of agricultural fresh produce (fruits and vegetables) in the U.S. have changed drastically over the past century. Vegetable and fruit production has become the frontier of agricultural research, a major part of the economic backbone of the country, and part of a more commonly consumed healthy diet in the U.S. in recent years [1]. A recent report indicated that in 2017, the U.S. fruit and vegetable industries contributed about $57.2 billion in market value, of which vegetables, melons, and potatoes constituted 30% [2]. Increasing market demand has not only called for intensifying domestic production, but has also made room for increasing foreign imports [3]. As a result, the fresh produce supply chain has become more globalized than ever before [4,5]. The free trade agreements in North America and around the world have provided further impetus in the last three decades towards globalized agricultural trade [4].

While in the U.S., fresh produce growers face increasing import pressure on the one hand, they also experience a variety of domestic, economic, social, and environmental pressures on the other hand. Common interest is growing among consumers to not only buy cheaper produce, but also safe, ecologically friendly, and sustainably grown fresh products. U.S. consumers are even willing to pay higher prices for organically produced food, locally grown food, and foods produced with a low carbon footprint [6,7]. Researchers have also reported that the market share of locally grown fresh produce has increased from 4 billion US$ to 5 billion US$ from 2002 to 2007 [8,9]. There is a growing awareness about the importance of social responsibility towards the ethical treatment of workforces throughout the fresh produce supply chain [10]. The shortage of domestic agricultural labor has forced U.S. growers to rely on expensive and more efficient foreign workers [11]. Immigration laws and policies are getting stricter to ensure the employment of domestic labor prior to the hiring of guest or foreign workers, and these policies, in turn, have complicated the recruitment process and eventually the costs of production. Environmentalists and public agencies have turned their attention to the harmful impacts of the extensive use of fertilizers, pesticides, and water [12,13]. Therefore, there is an ever-increasing expectation on the U.S. produce industry to make production not only cost-efficient, but also socially and ecologically sustainable.

An obvious question that has arisen is how sustainable the fresh produce industry is, especially amidst a growing number of economic, social, and environmental challenges. Rising production costs and import pressures are forcing the fresh produce industry to reconfigure itself. One of the important restructuring processes that is taking place within the U.S. fresh produce industry is large commercial farmers becoming larger and vertically integrating more than one segment of the supply chain [14,15]. Large commercial growers not only produce crops, but also operate their own packing houses; distribute; ship; export; import; engage in food service businesses; and, in some cases, sell directly to the large retailers [16,17]. The number of small growers has declined drastically, as they find it extremely hard to function on their own. A few remaining ones have made contracts with large commercial farmers or aggregators for harvesting and marketing. Small farmers mostly sell their produce directly to the consumers at roadside stalls, farmers' markets, etc. which contributed to only 1.9% of the total gross sales in the US in 2008 [18]. There are companies such as Driscolls' who work with other growers and market their produce. The above adaptive strategies are only a few examples of survival mechanisms under a broader set of sustainability challenges.

Considering Florida tomatoes as a case study, this paper focuses on the sustainability of an agricultural commodity that has historically enjoyed unique regional advantages compared to its production in the rest of the country. Florida, a south-eastern state of the U.S., ranked third (after California and Washington) and contributed almost 7% of the total U.S. income in terms of fruit and vegetable production in 2017 [2]. The seasonality of fruit and vegetable production in Florida is unique in the way that it grows more fresh produce during the winter when other U.S. states cannot produce due to low temperatures. For this particular reason, Florida growers receive premium market prices on tomatoes during the winter, which is $0.48/lb, while California growers receive $0.35/lb during the summer season [19]. Florida produces 300 different agricultural crops in the late fall to spring season (November to early June) [20], and 90% of the domestic fresh tomatoes in winter [19]. Tomato is the second largest agriculture crop in Florida after citrus (*Citrus* spp.), and contributes $426 million to the state economy. However, the following questions still remain unanswered: can Florida tomato growers continue to possess this advantage while meeting the societal demands for environmental sustainability, ethical labor responsibility, consumers' food safety, and sovereignty? While the fresh produce supply chain in the U.S. is becoming more global and vertically integrated, can the Florida growers sustain their Florida production base? Are there technological and policy remedies to help protect the regional advantage of the commodity in question? Answers to these questions are of interest not only to growers of the region, but also to public agencies, supply chain actors, and consumers.

There is no consensus among researchers as to how to address the question of the sustainability of an agricultural system or crop; yet, they have dealt with a range of aspects relevant to agriculture sustainability and the supply chain. A large number of sustainability studies have focused on farm-level production issues, with a special emphasis on economic and environmental performance [21,22]. In a recent study, Perez-Mesa et al. [23] investigated the sustainability strategies adapted by a small number of marketing cooperatives in Spain in response to retailers of fresh produce with a primary focus on economic profits. Vasileiou and Morris [24] argue that a sustainability assessment must cover the entire supply chain in order to ensure that the benefits of sustainability improvements made in one stage are carried across all stages of the supply chain. Some studies emphasize this network aspect of the supply chain, highlighting the relationship and operational linkage between different actors [23–25].

Sustainability studies that focus on farm-level issues have generally adapted one of the following three broad methodological approaches [22]: the first approach relied on life cycle analysis in order to estimate the environmental footprints of agricultural commodities [26,27]. The second category adapted multi-criteria decision tools based on stakeholder provided inputs with regard to the environmental, social, and economic attributes of the study commodities [28]. The third category used an extensive set of sustainability indicators either at the farm level or at the regional level to evaluate the progress of the system towards certain sustainability targets [29–31]. It should be noted that most of these studies focused on the environmental and economic impacts of resource use and input management [22], and stopped short of investigating the social and relationship aspects of the supply chain actors beyond the farm level.

This paper adapts a broader scope to analyze the sustainability of Florida tomato production by casting the production environment in a larger context that transcends beyond farm-level physical and economic conditions. We noticed that the published research on the overall sustainability of the tomato industry in Florida, including production analysis, fair trade, and climate change issues, is limited. Furthermore, there is a knowledge gap in the literature on how on-farm physical environmental factors intertwine with external forces (e.g., trade, immigration, government regulations, and social responsibility awareness), and, in turn, affect farmers' relationships with the larger supply chain. Thus, our study covers both on-farm sustainability aspects and off-farm network relationships between farmers and other stakeholders in the industry. We hypothesize that the sustainability of tomato industries in Florida needs more organized, strategic, and tactical planning to overcome internal and external challenges and to maintain the harmony of sustainability components both on the farm and with off-farm stakeholders. We set out to test this broad hypothesis by (1) evaluating different sustainability components of tomato production at the farm-level; (2) evaluating various on-farm and off-farm challenges of the tomato industry in Florida; and (3) proposing the best management strategies to improve the production, overall sustainability, and competitiveness of Florida tomato growers.

2. Study Approach

2.1. Conceptual Framework

A pragmatic definition of sustainability is often difficult to conceive; however, there is a common agreement that the sustainability discussion considers three dimensions of sustainable development, namely, environmental, economic, and social issues [22]. Sustainable development is "a concept based on intergenerational equity, i.e., the current generation must not compromise the ability of future generations to meet their material needs and to enjoy a healthy environment" [32]. In the context of fresh produce production, achieving inter-generational (current and future) and intra-generational (among all stakeholders of current generation) sustainability requires balancing between the three components, i.e., environmental, economic, and social dimensions. Environmentally speaking, sustainable crop production minimizes chemical use, reduces nutrient and pesticide run-off, improves soil health, reduces water quality degradation, and improves air quality by reducing the emission of harmful greenhouse gases and particulate matter [33,34]. Social sustainability in agricultural production provides better living conditions, safer workplaces, and equal job opportunities to the farmworkers (Economic sustainability improves the cost efficiency of a system and the economic viability of farms under a competing market environment, labor regulations, and product and environmental safety regulations [29,35].

Growers are not working in isolation, instead they are part of a larger system, called the global supply chain, which itself is often influenced by external drivers originating from within and outside of the production region. Previous researchers have, therefore, integrated two important concepts relevant to sustainability analysis [23,25], namely the sustainability in "production" [36] and the "commodity chain". Hopkins and Wallerstein [37] define the commodity chain as "a network of labor and production processes whose end result is a finished commodity". Taylor [38] characterizes a commodity chain as "a set of organizational networks clustered around one commodity or product linking households, enterprises, and state to one another within the global economy".

As a variant of the sustainable commodity supply chain (SCSC), Pérez-Mesa et al. [23] applied the "network" and "consumers' request" or preference aspects of the commodity chain to horticultural crops. Their model particularly considered the reciprocal relationship between producers and consumers. In one direction, there are all the farm-level challenges of producing 'fresh product' as desired by consumers. In the other direction, consumers send back 'requests' for eco-friendly, ethical, and affordable fresh food. All of the intermediate actors (distributors, wholesales, and retailers), their decisions (scheduling, packing, transportation, labelling), and infrastructure (cost storage, etc.) will need to be aligned with producers' capacity and consumers' choice.

We present in Figure 1 a modified version of Pérez-Mesa et al. [23] by expanding their SCSC model to explicitly include (a) various farm-level sustainability aspects concerning natural resources, climate, technology, input usage, and farmworkers; and (b) various external drivers including government, non-governmental organizations (standards, labor, etc.), and international and domestic competitors. This integrated model allows us to explore the interactions of on-farm socio-environmental factors and the external drivers in a holistic fashion and to assess the degree to which a region specialized in certain fresh commodity can continue to hold its production advantages while meeting their environmental and social responsibilities. The main premise of this analysis is that, despite the regional and seasonal crop advantages, the interplay of internal and external drivers presents a daunting challenge to Florida tomato farmers. Yet, the tomato industry is continuously strategizing its production and marketing strategies to stay ahead of the game.

2.2. Data Collection and Analysis

In this paper, we integrate the available published data with primary information collected directly from farmers and other supply chain actors, and government and non-governmental stakeholders. We specifically used the Google scholar, Web of science, and Scopus search engines to find research papers related to this study. Most of the production data were collected from the United States Department of Agriculture National Agricultural Statistics Service (USDA-NASS, Washington, DC, USA), USDA Economic Research Service (USDA-ERS, Washington, DC, USA), USDA Agricultural Marketing Service (USDA-AMS, Washington, DC, USA), U.S. Department of Labor (USDOL, Washington, DC, USA), U.S. Bureau of Labor Statistics (USBLS, Washington, DC, USA) and the Food and Agricultural Organization (FAO, Rome, Italy).

We applied a purposive sampling method to gather primary data from all stakeholders connected to the Florida tomato industry except for farmworkers. This method entails a deliberate selection of key informants representing private, non-government, and government entities who are knowledgeable about the industry field [39]. We first contacted three major fruit and vegetable growers' associations (tomato, strawberry, and fruit and vegetables) in Florida, which referred us to some of the growers as well as agricultural civic societies representing fresh produce certification, fair food, and labor welfare. Based on the literature review, we selected a few academic researchers who had extensively published about Florida tomato crops. A farmworkers survey was conducted with the help of a national public opinion research firm, Qualtrics, Inc., using their panel of respondents. This survey produced 35 completed responses from Florida. The data gathered from a total of over 70 stakeholders were mostly qualitative or descriptive and could not be subjected to probabilistic analysis. We viewed this approach as more suitable to the present study since the analysis was based on a combination of scientific, historical, behavioral, and opinion-based data. The above approach helped us develop a better understanding of the underlying causes, effects, relationships, and theoretical predictions of future sustainability of the Florida tomato industry. Table 1 presents the type and number of stakeholders surveyed for this study.

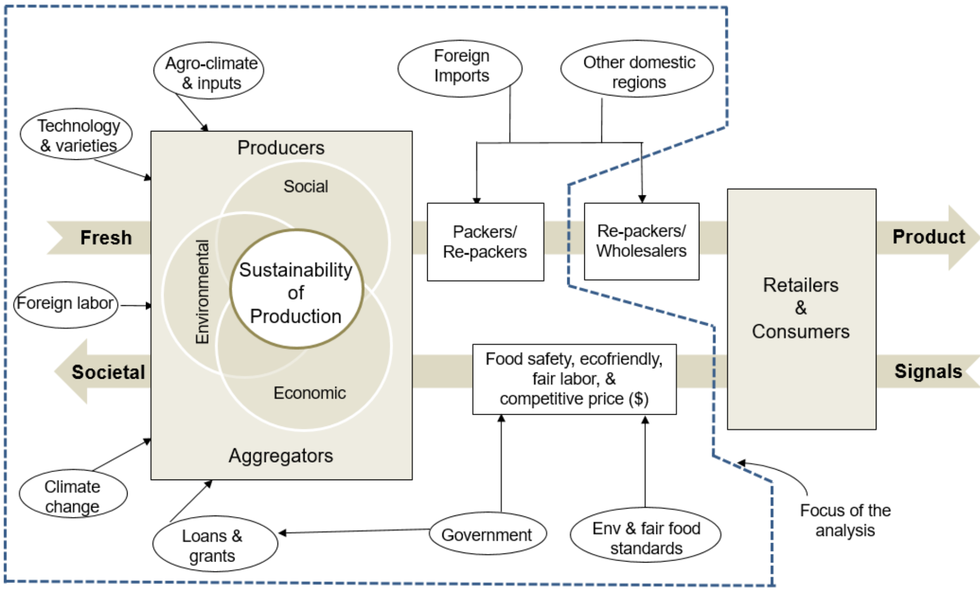

Figure 1. Conceptual framework for the sustainability analysis of the fresh produce supply chain.

Table 1. Sample of stakeholders interviewed for the study.

Stakeholders	Number	Notes
Florida growers' associations	2	Florida Fruits and Vegetable Growers Association, Tomato Committee, and Florida Strawberry Growers Association
Farmworkers' associations	2	Farmworkers' associations working in Florida
Producers	7	Includes some of the largest producers of Florida
Farmworkers and operators	35	Interviewed online via Qualtrics platform
Fresh produce certifiers	7	Organic, fair food, and food safety certifications
Packers and distribution centers	5	Operated by both producers and buyers
Local, state, and U.S. federal agencies	3	USDA Florida City, Florida Farm Bureau (Miami-Dade County Office), and Miami Dade-County Agricultural Manager
Food donation	1	Non-profit organization
Researchers	7	Academic institutions

We used semi-structured survey questionnaire while interviewing each stakeholder. Except for farmworkers, all other interviews were face to face or over the phone. The farmworkers' survey was conducted online. All stakeholders were asked to provide qualitative and quantitative information relating to issues relevant to them or the Florida tomato industry in general, e.g., tomato production practices, technology and varietal constraints, labor laws and ethical standards, immigration and trade laws, domestic and foreign competitions, etc.

3. Production and Utilization Trends of Tomato in the U.S. and Florida

Tomato is one of the most important horticultural crops worldwide, with a global production of 160 million tons in 2017 [40]. The U.S. is the fourth largest producer of tomatoes, with 10.9 million Mg of annual production [41]. Tomato is popular as a fresh vegetable, as well as in the form of processed products such as juice, paste, sauce, peeled, and concentrates. About 80% of tomatoes were consumed as processed products in the U.S. [42]. Various type of tomatoes produced in the U.S. include round, plum, grape, cherry, and heirloom. Among them, round and plum tomatoes enjoy the largest share of the market [19]. The United States also imports the largest fraction of round (50% of total import) and plum (43% total import) tomatoes from Mexico [43]. The U.S. imports about 81% of the total round tomatoes and 60% of the total plum tomatoes produced in protected structures in Mexico [43].

It should be noted that although the U.S. is one of the largest tomato producers in the world, the fresh market tomato production is still not enough to meet the domestic demand. Domestic tomato production serves only 40% of the fresh tomato demand in the U.S. [44]. Therefore, the U.S. needs to import tomatoes, mostly from Mexico and Canada, to meet domestic market demand. U.S. tomato imports from Canada have increased 20-fold from 1994 to 2016, whereas exports only increased by less than twofold (Figure 2). This is possibly because commercial tomato production in Canada has increased several times in the last few decades, mainly after the rapid and significant growth of greenhouse (controlled environment) production practices.

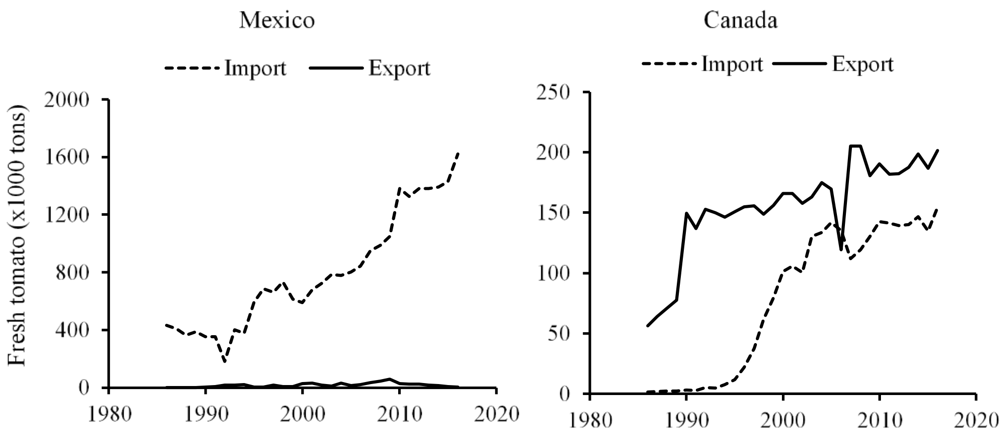

Figure 2. Fresh tomato trade analyses between the U.S. and Mexico and between the U.S. and Canada. Import and export data are presented in reference to the U.S. (Source: FAO).

California is the largest tomato producing state in the U.S. However, Florida is an important winter production area for fresh-market tomatoes. Florida supplies 90% of the domestic winter tomato production in the U.S., with over 11,331 hectares of production area and a market value of $262 million in 2017 [45]. Florida growers primarily produce round tomatoes, i.e., 69% of the total movement, irrespective of the market demand [19]. Among the total amount of round tomatoes harvested, 99.5% are harvested at the mature green stage [19]. The plum or roma tomato share is 19% of the total tomato movement in Florida, which is closely followed by grape tomato at 10% [19]. The retail industry in the U.S.

generally purchases tomato types depending on customer preference, and there is currently an increased consumer interest in a wider range of tomatoes. Our interviews suggested that Florida's lack of tomato diversity is making retailers consider sourcing different categories of tomato from other states. Therefore, current buyers of Florida tomatoes are restaurants, who mostly prefer round tomatoes harvested at the mature green stage.

4. Sustainability in Tomato Production

In this section, we characterize three dimensions of sustainability for Florida tomato production from the point of view of farm-level operations (Figure 1), which later helps set the stage for evaluating the effects of various internal and external drivers of sustainability. Under each dimension, we attempt to describe those farm-level socio-environmental contexts and tomato-specific attributes that influence different sustainability criteria, including few or no environmental impacts, profitability, worker and farmer welfare, and consumer safety, among others.

4.1. Environmental Sustainability

A stricter definition of environmental sustainability calls for the minimal use of synthetic chemicals, no adverse impacts on on-site or off-site natural resources and ecosystems, and long-term soil health. However, tomato is a high-value vegetable crop in Florida, and requires the intensive application of synthetic fertilizers during production. Due to the porous oolitic limestone characteristics of South Florida soils [46] excess nutrients run off to the adjacent water bodies, resulting in water quality degradation [47]. High nutrient loading into freshwater systems, coupled with favorable Florida weather conditions (warm temperature, bright sunlight), often promotes the formation of harmful algal blooms, causing major human health, environmental, social, and economic problems [48,49]. Agricultural operations and other sources contribute approximately 600 metric tons of total phosphorus into Lake Okeechobee, Florida (the largest lake in the southeastern U.S.) every year [50]. Florida farmers are also following best management practices (BMP) for tomato production as recommended by the Florida Department of Agriculture and Consumer Services (FDACS). The major goal of the BMP scheme is to protect water resources and to manage fertilizer application, irrigation, and the water table. A total area of 933,683 acres (377,848 hectares) under row field crops in Florida had BMP implemented [51]. Currently, Florida BMP is following 4R techniques (right source, right rate, right place, and right time) to improve fertilizer management at the farm level. Additionally, Florida farmers are using advanced technologies (tensiometers and laser levelling) for improving irrigation efficiency, drones for detecting pests and diseases, and GPS-enabled auto driving tractors for precision farming.

Western flower thrips (*Frankliniella occidentalis*) are an important pest of tomato in Florida as they act as a vector for *Tomato spotted wilt virus*, *Impatiens necrotic spot virus*, and other tospo viruses. This invasive insect pest has the capability to develop high resistance to most insecticides used for its management [52]. Excess application of chemicals to control this pest not only reduces biodiversity but also disturbs the ecological balance and creates conditions favorable for the development of pesticide resistance [53,54]. Hence, farmers are advised to follow crop rotation, cover crop establishment, and other cultural practices to break the pest life cycle.

4.2. Economic Sustainability

Economic sustainability depends on the long-term management of a production system to avert numerous risks and uncertainties [55]. The paradigm of economic sustainability is to improve overall tomato industries, where if one farm fails to perform, it will move to more efficient farmer and eventually improve the overall sustainability. Florida tomato cropland has not only shrunk over the years, but also has concentrated into larger farms. Tomato is a very input-intensive crop, and annual production costs are close to $37,000 per hectare [56]. The selling price per carton (11.34 kg per carton) of tomatoes received by the farmers was $11.83 [56], which amounted to around $1 per kg of tomato. However, the average tomato price in the retail market was reported as $2.89 per kg [19]. Basically, growers received about one-third of the retailing market price. The USDA-NASS [57] reported that in 2018, the average tomato yield in Florida was about 32 tons per hectare, which amounted to an average gross revenue of $33,400, less than the estimated costs of production during the same year [56]. On the other hand, selling tomatoes at a profitable price is often difficult because of the import pressure from Mexico and Canada. Therefore, the only way to improve net profits in the future is to increase productivity and reduce the production costs. High-yielding tomato varieties (such as HM 1823, BHN varieties) with judicious fertilizer application and better irrigation and pest management strategies under favorable weather conditions can be used to achieve maximum yields and maintain overall sustainability. The cost of production largely depends on the farm size and the input costs. The hiring of cheaper domestic labor can work as a potential means to improve the economic sustainability of tomato farms. Besides productivity, the timing or seasonality of crop harvesting can also improve profitability. For instance, during the transition period, when the production of tomato slows down in California and Florida starts to pick up, growers received a premium tomato price for every kilogram. Figure 3 shows that from July–August to March–April, the retail market price for tomato stays higher in the U.S. as compared to the rest of the year, which is the Florida production season. The highest retail prices in the U.S. are observed during December and January; therefore, tomato harvesting during that time window would maximize the profit for Florida farmers. Imports from Mexico start picking up from September, and reach a maximum point from January to April. This increased supply of imported tomatoes might be a reason for the price drop after January. Additionally, market demand and supply play an important role in the tomato market price. For example, tomato production in Florida was low in early 2018 due to untimely rain and warm winter conditions. Imports from Mexico were also lower than the normal quantity in the winter of 2018 [58]. Hence, Florida producers who harvested early tomato crops during the winter of 2018 received a higher market price [58]. Our own interviews with Florida tomato growers revealed that many major tomato growers–shippers of Florida, namely Del Monte, Harllee Packing, Big Red Tomato Packers, and East Coast Brokers exited from the Florida tomato industry due to low profitability, cheaper import pressure, and the development of the real estate sector in agricultural lands [58–60].

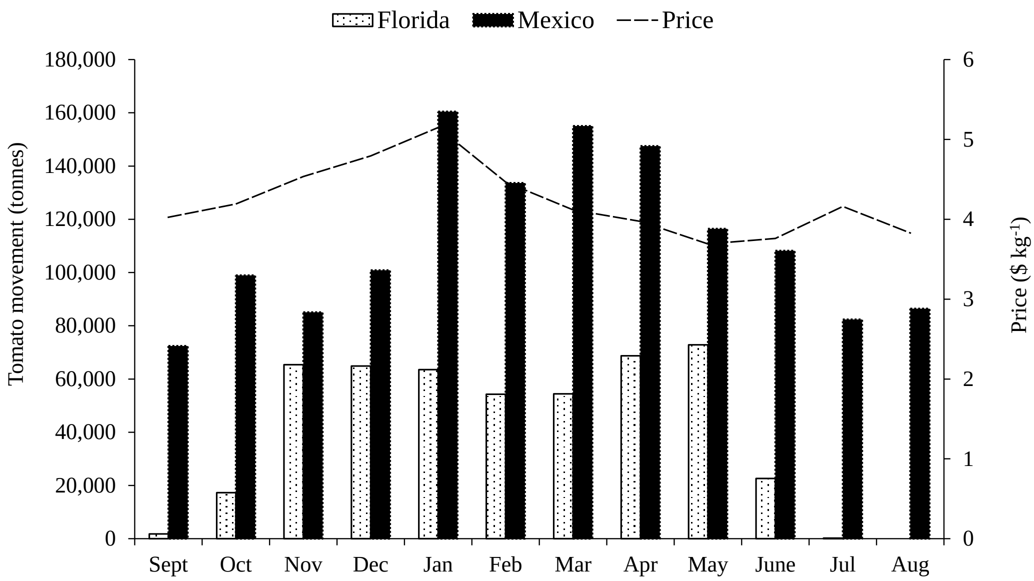

Figure 3. Monthly price and movement of tomatoes in Florida and Mexico during the 2018 production season (Source: USDA-AMS, USBLS).

4.3. Social Sustainability

Fresh produce industries support both farm families and hundreds of other associated families by providing jobs and other facilities throughout the supply chain. As the majority of tomatoes produced in Florida are for fresh consumption, harvesting is done mainly by hand picking and therefore, the recruitment and employment of seasonal agricultural workers is crucial during harvesting. Other farming operations such as the transplanting of seedlings and the staking and tying of the tomato plants also requires a significant amount of labor force. Historically, farmworkers were under-paid; under-fed; and subjected to harassment, forced labor, and abuse [61].

In order to improve the living conditions of farmworkers and the social sustainability of the Florida tomato industry, the fair food program was started in 1993 by farmworkers of Immokalee, Florida. Almost 90% of the Florida tomato growers and 20% of the buyers are currently participating in the fair food program [62]. Fair food certification is managed by a farmworkers organization, called the Coalition of Immokalee Workers (CIW), and a third-party organization named the Fair Food Standard Council (FFSC). The participating buyers will pay penny per pound extra, which will eventually get distributed to the farmworkers as a bonus in addition to their normal wages. The cost of obtaining this certification is free. The main objective of this program is to improve the living conditions of tomato farmworkers. The fair food program also prevents the overfilling of the bucket during tomato harvesting, as the wage of tomato harvesting crews is mostly based on a per bucket basis. This action alone has led to an increase of farmworkers' income by ten percent. Additionally, the farmworkers are directly employed by the growers, eliminating the supervisor post to improve the efficiency of the system and to reduce exploitation. The FFSC helpline is available for the farmworkers to report any kind of complaints such as sexual harassment, forced labor, and more.

Migrant farmworkers are protected by the U.S. Migrant and Seasonal Agricultural Workers Protection Act (MSPA) for their wages, transportation, and housing. This law is managed by the U.S. Department of Labor. Under this law, growers are required to provide farmworkers with access to restrooms, handwashing stations, and shades in the field. Farmers also need to provide personal protective equipment to the workers for safety. The agriculture industry imposes different kinds of health hazards such as exposure to heat, pesticides, fertilizers, chemicals, solvents, cleaners, heavy machinery, and plant allergens while working in the field [63]. Growers are expected to educate farmworkers about the work-related risks through training provided by a third party such as the Florida Department of Education's Farmworker Career Development Program (FCDP). In addition, educational facilities are also available for children of the farmworkers. The Redland Christian Migrant Association (RCMA) provides childcare and early education to the migrant farmworkers' children. Collectively, there are a number of initiatives in place in the Florida tomato industry that have made some significant improvements in the ethical treatment of farmworkers.

5. Internal and External Drivers Influencing the Sustainability of Florida Tomato Production

After broadly characterizing the three dimensions of sustainability, we will now turn to the various internal and external factors that influence farmers' decisions and their ability to maintain farm-level sustainability (Figure 1). These factors include: (i) agro-climate, (ii) technology, (iii) foreign labor, (iv) climate change, (v) loans and grants, (vi) food safety regulations, (vii) other produce certifications, (viii) foreign imports of tomatoes, and (ix) the domestic tomato supply chain.

5.1. Agro-Climate

Tomato production in subtropical Florida has many challenges. High humidity, prolonged dew, and frequent rainfall often results in higher disease incidence and severity than in other climates. During mild winters, some agricultural pests remain active throughout the winter, and result in earlier pest outbreaks during the subsequent growing season [64]. High summer temperatures in subtropical Florida can lead to poor fruit color, fruit damage (sunscald), and discolored pericarp [65]. Sunscald in tomatoes reduce their marketability. Eventually, high summer temperatures and humidity lead to poor pollination and reduced fruit set, limiting the production season. Alternatively, the cool early spring and late fall temperatures commonly found in subtropical Florida may also negatively impact fruit quality, increasing cat-facing; yellow shoulder disorder; or, in extreme cases, cause fruit chilling injury [65]. Finally, spring temperature fluctuations are often rapid and drastic, inhibiting plant acclimatization and increasing plant stress. All of these limitations require Florida tomato growers to employ innovative production practices to maximize plant health and productivity in order to achieve long-term sustainability. Some of the farmers we surveyed had tried grafting and low-cost high tunnel technologies in the past for maintaining optimum yields. However, Florida is susceptible to hurricane and tropical storms, making such protective structures vulnerable to storm damage.

Pest control is a major challenge for Florida growers. Pesticides contribute to 12% of the total cost of production at the farm level. As mentioned before, one of the main pests of tomato in Florida is thrips (*Frankliniella schultzei*). They not only feeds on host plants, but also transmit tospoviruses. Furthermore, weeds not only compete for space, light, nutrients, and water with tomato plants, but also serve as alternate hosts for different pests and diseases. For instance, nightshade, Spanish needle (*Bidens pilosa*), garden spurge (*Chamaesyce hirta*), lambsquarters (*Chenopodium album*), hairy indigo (*Indigofera hirsuta*), wild mustard (*Sinapis arvensis*), and sow thistle (*Sonchus oleraceus*) are potentially alternative host for the sweet potato white fly, which transmits *Tomato Yellow Leaf Curl* (TYLC) *virus* to tomatoes [66].

5.2. Technology

Tomato growers in Florida use various sustainable production technologies to increase production efficiency and reduce costs. Farmers use advanced irrigation systems such as sprinkler irrigation, pivot irrigation, drip irrigation, and seepage irrigation. It has been reported that drip irrigation or micro-irrigation is the most efficient irrigation for tomato production among all the other methods. Water use efficiency (WUE) of drip, sprinkler, and seepage irrigation in Florida are about 90%, 75%, and 20% to 50%, respectively [67]. The timing or scheduling of irrigation is also very important to improve WUE, and farmers are using different tools (such as the Florida Automated Weather Network developed by the University of Florida) to improve it and to schedule irrigation whenever it is needed. Soil moisture sensors helps to maintain the soil moisture level within the upper and lower limit, and thus prevent inefficient water application [68,69]. Farmers have also adopted laser field levelling to ensure a better distribution of irrigation water, uniform germination, and uniform fertilizer distribution by fertigation. Farmers are using automatic tractors for precise land preparation, equally spaced straight row construction, precise seed application, chemical application with minimum overlapping, and variable rate technology to facilitate site-specific nutrient application.

Tomato varieties that are available in Florida are bred for higher yields and shelf life. However, according to our stakeholder's survey, customers prefer texture, taste, and flavor to better shelf life. The imported varieties of tomato from Mexico give consumers access to different categories of tomato with variable quality. Hence, the plant breeders in Florida have focused their effort on developing varieties with better quality rather than improving shelf life [70]. Most of the Florida tomatoes are harvested at the mature green stage and ripened with the help of ethylene, while the tomatoes imported from Mexico are grown under protected structures and are vine-ripened. Vine-ripened tomatoes have better taste and flavor than tomatoes harvested at the mature green stage, and thus have higher market demand. Additionally, warmer temperatures have posed an additional challenge to Florida growers while selecting varieties. Larger growers have developed proprietary heat-resistant varieties (personal communication with farmers). Public and private breeding programs have also developed successful heat-resistant varieties such as HM1823 and Solar Fire, which are increasingly replacing traditionally known varieties such as FL 47. The major challenge at hand for breeders is to continue to improve heat-resistant yet fine-quality tomato varieties.

Finally, protected structures including greenhouses, shade houses, and high tunnels offer significant protection against insect pests and diseases, and are a means to extend the production season. According to Asci et al. [71], greenhouse tomato production costs 32 times more than open field production, specifically because of the initial costs of construction (1 hectare of protected structure costs $2.42 million) and the higher chemical inputs. However, indeterminate tomato varieties are commonly grown in greenhouses and can produce almost 15 times higher yield than open field conditions [71]. Controlling temperatures in greenhouses is very important for a good marketable yield of tomatoes in Florida. Due to the warm climatic condition, the temperature inside of greenhouses in south Florida reaches higher than the optimum temperature range for tomatoes. Some large Florida farmers had tried protected agriculture, but have discontinued it because of high costs, no premium remuneration, the lack of government support, and the vulnerability to windstorm.

5.3. Foreign Labor

Tomato production in Florida is highly labor intensive as it involves the hand transplanting of tomato seedlings, the staking and tying of tomato plants in the field, and the harvesting of tomatoes by hand picking. Labor constitutes almost 30% to 40% of the total tomato production costs in Florida [56]. From our interviews, we found that the competition of local labor with other industries such as restaurants and construction often limited the availability of the domestic work force for tomato production in Florida. Almost half of the American farmworkers are undocumented immigrants [72], and undocumented migrant workers constitute about 4% to 6% of the total farmworkers in the Florida agricultural industry [73]. Due to strict border laws, the growers are forced to replace the cheaper undocumented labor with expensive H2A or guest labor. The hourly wage of guest workers is almost $4 per person higher than domestic workers [74]. The pre-employment cost of the H2A immigrant workers is $2,000 per person, which includes transportation, visa sponsorship, advertisement, housing, and more [75]. Employers also need to guarantee 75% of the total hiring contract hour to the H2A farmworker.

5.4. Climate Change

Climate change is a major consideration for agricultural sustainability, and it affects the Florida tomato production in multiple ways. Ayankojo and Morgan [76] predicted that warmer air temperatures in the early planting season could negatively affect fruit formation and lower the average tomato yield by anywhere between 52% and 85%. Furthermore, the El Niño Southern Oscillation (ENSO) is one of the determining factors influencing the weather in Florida. The warm El Niño results in a cool, wet winter with fewer tropical storms, while the cool La Niña results in a dry, wet winter with more tropical storms [77]. The tomato yield was low in Florida in 2015–2016 due to the strong influence of El Niño [78,79]. The farmworkers' survey responses suggested that almost 89% of farmworkers felt that the temperature was getting warmer, and 77% agreed that it was becoming increasingly difficult to work in the field under the hot sun. This result was consistent with previous studies. For instance, Mac et al. [80] reported that more than 50% and 70% of the sample farmworkers in 2012 and 2013, respectively, had experienced an increase in their body temperature above the threshold limit of 38 °C.

5.5. Government Loans and Grants

According to the USDA-AMS, tomato is a specialty crop, and in the U.S., specialty crops normally do not qualify for direct government subsidies. The implementation of new technologies such as greenhouse production, the installation of improved irrigation system, and the adoption of other high-end technologies needs large amounts of initial investment, which is often considered to be risky and beyond the reach of some farmers. Government assistances is only in the form of low-interest loans and subsidized premiums for crop insurance. The USDA Farm Services Agency (FSA) provides subsidized long-term loans to farmers for specialty crop production [81].

The Farm Services Agency (FSA) also provides disaster assistance for specialty crop growers. For example, the qualified farmers who lost a minimum of 50% of the expected crop yield or who could not plant 35% of the area due to disaster were eligible to receive indemnity payments [82]. Specialty crop growers also receive marketing assistance, crop insurance assistance, export promotion, and technical assistance to expand the market [82]. However, the total amount of direct government support to Florida tomato growers pales compared to the capital subsidy that the Mexican growers receive, making high-end tomato production technology costs prohibitive.

5.6. Food Safety Regulations

Food safety is one of the major concerns in the U.S. The U.S. Centers for Disease Control and Prevention (CDC) estimates that each year, 48 million people get sick from foodborne illness, 128,000 get hospitalized, and 3000 die in the U.S. [83]. Florida is the first state in the U.S. to implement mandatory food safety in production, packing houses, and supply chain systems. Tomato GAP (T-GAP) certification audit and inspection is performed by FDACS; hence, almost all the tomato farms in Florida are T-GAP certified. Florida farmers also follow the food safety certification required by buyers (e.g., retailers and restaurants), a practice that eventually minimizes food waste related to the foodborne illnesses and food recall. Noncompliance with proper food safety not only causes economic loss, but also damages the reputation of the company. Therefore, farmers, buyers, and other supply chain actors follow the food safety processes very strictly. The Food and Drug Administration (FDA) manages the Food Safety Modernization Act (FSMA), which undertakes mandatory audits to ensure food safety. However, numerous licensed food safety certifiers are available to conduct food safety audits. Any farm which sells less than $25,000 worth of products annually is exempted from mandatory FSMA audits, but is still subject to state mandatory food safety audits, e.g., Florida T-GAP and FDACS agricultural marketing orders [84]. A common concern expressed by the sample farmers was that multiple certification requirements are time consuming and expensive, particularly for small farmers.

5.7. Other Produce Certification

As indicated before, the Coalition of Immokalee Workers started a special program in 1993 to improve wages, living conditions, and safety in work environments for farmworkers [85]. It also helped to facilitate the Fair Food Certification Program [62], which increased farmworkers' wage by nearly $60–80 per week [86]. Almost 87% of the Florida farmworker survey participants agreed that there was an increase in their wage due to the implementation of fair food certification. After the initiation of fair food certification, the program distributed $26 million in premiums on top of the farmworkers' regular wages [62].

Currently, the U.S. has 202 ecolabels [87]. Rihn et al. [88] suggested that consumers preferences were impacted by ecolabels, and that they were aware of heirloom and non-GMO ecolabels. Numerous ecolabels available on the market might confuse consumers, and proper awareness is required to improve consumers' perception towards different ecolabels. According to Seufert et al. [89], organic farming generates a 20% lower tomato yield than conventional farming due to high pest pressure. Some small farmers have successfully adopted USDA organic certification by selling produce directly to consumers for a premium price through food stands or farmers' markets. This approach may not necessarily work for large-scale commercial production.

5.8. Foreign Imports of Tomato

The tomato industry in Florida is suffering due to the import pressure from Mexico and the loss of farmland due to real estate development. The North American Free Trade Agreement (NAFTA) between the United States, Mexico, and Canada came into force on 1 January 1994. Tomato production in Florida decreased by almost 50% from 1991 to 2017, while the import volume increased almost fivefold (Figure 4).

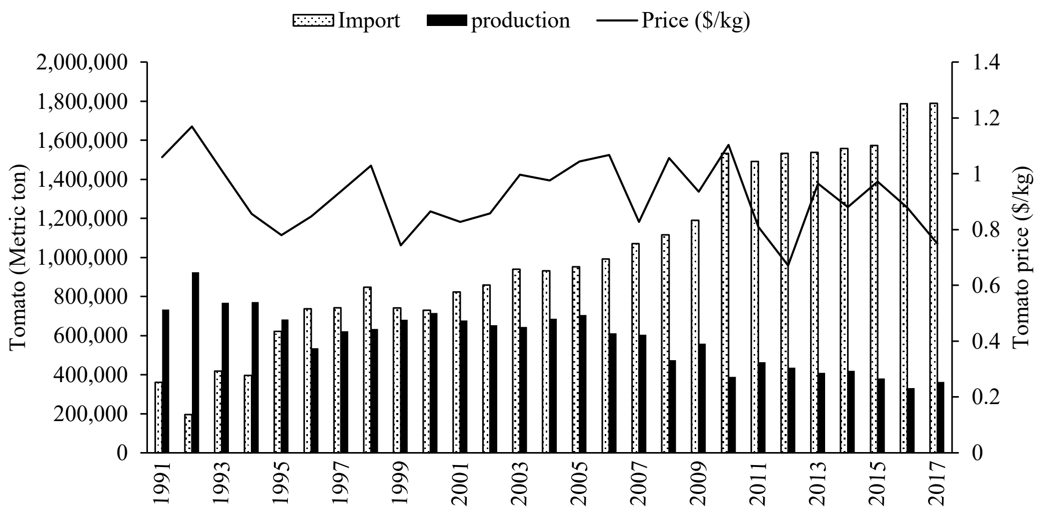

Figure 4. Production volume in Florida, import volume from Mexico, and the price of tomatoes in the U.S. from 1991–2017 (Source: USDA-NASS, USDA-ERS, and USDOC).

Cheaper tomato imports from Mexico and other countries have also reduced the U.S. market prices for tomatoes by 30% over time (Figure 4). The volume of tomatoes imported to Florida have also had sharply increased (i.e., by 30% from 2009 to 2010) and stayed at that elevated level afterwards because of the unexpected freezing damage in 2010 (Figure 4). Based on our discussion with two large tomato growers, the loss of Florida production volume and the inconsistency in the supply have adversely affected the long-term commitment between Florida farmers and retailers and other market stakeholders.

Two main sources of U.S. tomato imports are Mexico and Canada. Canada exports open field tomatoes to the U.S. market from July to September (Table 2). Hot house Canadian tomatoes are exported to the U.S. market throughout the year, except during extreme cold months, i.e., January–February. Within the U.S., California supplies tomatoes during the summer, i.e., from May to November, while Florida supplies them during the winter, i.e., from October to June. Sinaloa, Mexico exports tomatoes from December through to April, which coincides with the main growing season of Florida. Baja California, Mexico supplies tomatoes from May through to December, the same time as the California production season. Hence, Florida and California are in direct competition with Sinaloa and Baja California, Mexico, respectively.

The input cost in Mexico is cheaper than in Florida or California [93,94]. Additionally, the Mexican labor hourly wage is seven times cheaper than the U.S. hourly wage [93]. Furthermore, Mexican farmers receive large subsidies from the government for constructing greenhouses, high tunnels, or any other protected agriculture to grow specialty crops [95]. The Mexican agricultural support program contributed 263.7 billion pesos of subsidies from 2013–2016 [95]. Their protected agriculture (shade houses, high tunnels, and greenhouses) is capable of generating a 3–4 times higher yield than open field production [96]. It not only ensures production volume, but also helps to maintain the consistent quality and supply of the produce. The acreage under tomatoes in Mexico has decreased by 48% from 1990 to 2012–2013 due to the increase in productivity and the implementation of improved technology for producing tomatoes [96].

Table 2. Timeline of tomato shipping in North American countries (USA, Canada, and Mexico) from open field production and protected conditions (shade house, greenhouse, and tunnels). (Source: information derived from [90–92]).

Country	Places	Open field	Protected condition
U.S.A	California, U.S.	May to November	Throughout the Year *
	Florida, U.S.	October to June	
	Other states of the U.S.	July to September	
Mexico	Sinaloa, Mexico	December to April	Throughout the Year ¥
	Baja California, Mexico	May to December	
Canada		July to September	Throughout the year except extreme cold months that is January and February

* For entire USA, ¥ For entire Mexico.

5.9. Tomato Supply Chain and Recent Changes

Normally, the domestic end to end supply chain consists of growers, packers, shippers, re-packers, brokers, wholesalers, food service, and retailers. According to some of the sample respondents, food service is the main buyer of Florida tomatoes. For instance, from 75% to 80% of Florida round tomatoes go to restaurants, schools, and hospitals. Traditionally, food service companies buy round Florida firm tomatoes for slicing and use in burgers and sandwiches. However, some of the recent changes in the food service industry are affecting Florida growers. The industry is shifting its preference from round to roma tomatoes. For instance, fast food chain restaurants including McDonald's, Wendy's, and Subway have partially switched their demand from Florida round tomatoes to roma tomatoes from California or greenhouse-produced tomatoes from Mexico. Around early 2021, the above changes in the supply chain had cost Florida growers a loss of 60 truckloads per week of tomato demand. Furthermore, during the COVID-19 pandemic, 25% to 30% of restaurants went out of business, affecting demand for Florida tomatoes drastically.

For more than two to three decades now, the fresh produce retail industry and food service providers have been consolidating. Large retailers have consolidated due to change in consumer preferences, changes in the patterns of grocery sales, and competition [97]. Due to increasingly busy lifestyles, consumers prefer to buy 'ready-to-eat' foods over raw products available for cooking at various grocery stores. Additionally, the overall growth of the grocery or food retail market is very slow, i.e., almost 1% over a decade [97]. Therefore, the consolidation of food retail with mass merchandising (e.g., Target, Walmart, etc.) and warehouses (e.g., Costco, BJ's, and Sam's club) have helped to withstand the market competition [97]. Consolidation is also taking place within the food service industries. A popular example was Yum Brands Inc., which consolidated four major fast-food chains including KFC, Taco Bell, Pizza Hut, and The Habit Burger Grill. The consolidation of retailers and food service organizations has resulted in an oligopolistic market structure, where a few buyers buy the largest quantity of the produce, a practice that gives them bargaining power over the supply chain components. As a result, the prices that the farmers are obtaining are decreasing. According to the report published by Oxfam America [14], the grower–shippers received only 25% of the retail tomato price in 2001, a sharp decline from 41% in 1990.

Similar to the retailers, growers are also consolidated and vertically integrated. Large growers in Florida have vertically integrated their operations, including production, packing, repacking, selling, and other operations. Only nine grower–shippers contribute more than 70% of the total tomato movement in Florida [98]. Selling produce through repacking facilities, which acts as a shock absorber in the tomato supply chain, has also helped the Florida tomato industry to stay competitive in the market [14].

6. Discussion and Recommendations

As evident from our analysis, for more than a decade, Florida tomato growers have been feeling the pressure from multiple angles, particularly climate shocks, increasing pests and diseases, declining market shares and prices, increasing labor and input costs, and the increasing expectations of environmental and ethical responsibilities. This raises the question of how they have been coping with these changes and whether Florida farm production remains resilient and sustainable. In this section, we will discuss some of the existing and future strategies that growers, the tomato industry, and the U.S. government have at their disposal in order to cope with the pressures of multiple internal and external shocks.

6.1. Development of Resistant Varieties

Florida's climatic condition favors pest and weed infestations. Trials were conducted to test the adoptability of commercial tospovirus-resistant varieties of tomatoes containing the Sw-5 gene (e.g., Quincy, Dixie Red, Southern Ripe, BrickYard, etc.) in South Florida [99]. Other varieties are also available that are resistant to verticillium wilt, fusarium wilt, nematodes, bacterial spots, and other common diseases. Some large growers have already developed their own proprietary heat- and disease-resistant varieties, while medium and small farmers have to rely on public breeding programs. Many farmers have already adopted heat-tolerant varieties to prevent yield loss due to the changing climate. The very low elevation of South Florida makes it highly prone to sea level rise, which leads to saltwater intrusion and the salinization of farmland. Deeper wells have higher salt concentrations than shallower wells in Florida. Hence, the need for the development of salt-tolerant varieties is of critical importance to sustaining tomato production in the future. More research is necessary for developing such varieties.

6.2. Protected Agriculture with Structural Modifications and Hydroponics

Tomatoes are mainly produced in open fields in the U.S. Canada started to produce tomatoes in greenhouses in the mid-1990s and became the largest producer of greenhouse tomatoes in North America. Mexico and the U.S. also started tomato production under protected agriculture, this reduced the market share of the open field tomato. Before 2005, greenhouse tomatoes contributed to 37% of the total fresh tomato retail market in the U.S. [90], and this level has increased since then. The U.S. annually imports 0.5 million tons of tomatoes produced under protected agriculture [19].

Greenhouses have the potential to improve the productivity of fresh tomatoes and net profit compared to open fields [71]. Hence, greenhouse can be a potential solution to improve domestic tomato production. However, the main barriers for greenhouse production are high labor and capital costs. Unlike in Mexico, in the U.S. and Florida, growers do not get the same level of capital subsidy from the government. If the cost of labor can be reduced in greenhouse production through the application of artificial intelligence services to automate tasks, the net return could improve. Cheaper shade houses or screen house structures with natural ventilation are gaining popularity in tropical climates for their potential to minimize the insect population while optimizing the production [100]. The cooling of greenhouses, i.e., mechanical ventilation or evaporative cooling in hot and humid climates similar to Florida, is very important for successful tomato production and quality [101]. According to Jain and Tiwari [102], evaporative cooling can reduce the inside temperature of a greenhouse by 4 to 5 °C. Passive cooling can be used by following constructional modifications: a taller greenhouse with a 3 to 4.5 m ridge height, a 27 to 30° roof angle, a ventilator area equivalent to 20 to 25% of the floor area, and openings at the top and side of the greenhouse for air circulation [103].

Vertical agriculture under protected structures with hydroponic growth media might be another potential solution to meet the domestic tomato yield gap. It also helps to intensify the yield under the same piece of land with the same structure. All of the essential mineral nutrients are needed to supply hydroponic tomato production. Vertical farms can be housed in different abandoned urban buildings.

6.3. Anti-Dumping Laws

The tomato suspension agreement is an agreement between the U.S. Department of Commerce (USDOC) and the growers or exporters of Mexico to suspend the anti-dumping investigation of the U.S.A. against Mexico. The first suspension agreement became effective on 1 November 1996. According to the anti-dumping suspension, the exporting country, primarily Mexico, needs to sell tomatoes at or above the reference price to eliminate any harm to the domestic industry of the U.S. A new tomato suspension agreement was signed between the USDOC and the Mexican tomato industry in 2019. This agreement authorizes U.S. officials to audit (quarterly) 80 Mexican tomato growers and U.S. sellers [104]. The Florida Tomato Exchange requested to continue the anti-dumping investigation against Mexico. Under this agreement, if the investigation finds that the Mexican growers are dumping tomatoes into the U.S. market, then the tomato suspension agreement will continue, which will trigger the appropriate import duties. On the other hand, if the investigation concludes that there is no dumping of Mexican tomatoes into the U.S. market, the suspension agreement will be terminated, and free trade will resume. This agreement is an economic necessity, particularly for those Florida growers who might limit their production to Florida and other states within the U.S. The agreement creates a level playing field for the U.S. growers. However, according to the sample growers, Mexican growers have kept their price at just around the reference price (e.g., $8.30 per carton of roma tomatoes in 2021), which Florida growers find it extremely difficult to compete with.

6.4. Governmental Subsidies for Large Farm Construction

Subsidies can help the farmers to implement high-end technologies such as protected structures, efficient irrigation systems, and better farm machinery, which can eventually increase farm productivity and improve overall sustainability. As mentioned before, the Canadian and Mexican governments have invested heavily into protected agriculture. It was reported that the Mexican government spent 263 billion pesos (equivalent to $11.62 billion) from 2013 to 2016 to provide subsidies for the modernization of agriculture, producing marketing, support for crop production, and the improvement of postharvest methods [95]. However, in the U.S., government support for farming is traditionally restricted to certain commodity crops and, more recently, to conservation practices. The modernization or implementation of new technologies for fresh produce production is very expensive. For the long-term stability of the U.S. fresh produce industry, a combination of anti-dumping laws and government support for protective agriculture may be necessary. While a large-scale investment in a short time could be a huge burden on taxpayers, a phased investment over a longer period of time would provide needed stability for Florida and U.S. growers.

6.5. Diversified Market Strategies

Produce marketing is mainly categorized as indirect marketing and direct marketing. Indirect marketing follows the principle of producers selling their farm produce to the consumers through brokers, repackers, retailers, and other supply chain components. However, with direct or alternate marketing, producers sell their produce to consumers directly at farmers' markets, food stands, and u-pick operations. Large growers mostly depend on the retail, wholesale, and food service markets. The main reason for large growers selling produce directly to retail stores or other big markets is that they mostly have contracts with them [105] (personal communications with sample growers). However, during our primary interview and stakeholder engagement meetings, both large and small buyers express that selling at alternative markets and finding new product streams have become essential for their economic survival. In particular, large Florida fresh produce growers have increasingly consolidated their operations over the years to reduce middlemen and improve profitability.

Growers also sometimes sell produce at alternate markets or donate produce to food banks when a buyer rejects any large crop load or there is an excess amount of produce. Large commercial growers often sell their excess agricultural produce at farmers' markets (FM) or through other direct market channels to avoid food waste and cut costs. Adams and Adams [106] reported that 62% of a sample of Florida participants purchased fruits and vegetables frequently from FM, as those products were cheaper and easily accessible. About 86% of the same sample's participants were willing to pay extra money for locally grown fruits and vegetables.

For small and medium farms that are close to urban areas, they may find u-pick farm operations or selling at farmers' markets a viable alternative. However, only 3% of the participants bought fruits and vegetables from u-pick operations [106]. A growing number of farmers' markets have started operating in the last decade. The Florida Department of Agriculture and Consumer Services maintains 12 farmers' market in Florida, which are equipped with refrigerators, packing houses, coolers, and truck weighing scales. These facilities also provide produce brokerage, shipping/freight, and offices. It operates 24 h a day during crop production season only, and generates about $225 million in annual revenue [107]. After the commercial harvest of the produce, volunteers come to pick the leftover produce from the field and send it to food banks, which eventually distribute it to needy people. When growers donate packaged food to food banks, they get a tax break on the market price of that load.

7. Conclusions

In this study, we analyzed the sustainability of Florida tomato farming by taking into account a broader perspective that covered forces and drivers beyond the farm-level environment. The decision to work towards sustainability is not just a farmers' choice but a societal imperative, signals for which are increasingly coming from consumers and civic societies in general. The long-term survival of the tomato industry therefore depends on how well it is able to cope with farm-level challenges and opportunities, as well as external factors. Therefore, we examined various drivers, actors, and institutions operating along the broader tomato supply chain.

Tomatoes are one of Florida's recognized signature crops, and Florida is the main domestic source of fresh winter tomatoes in the U.S. Like other crops, Florida tomato growers face numerous production challenges, including growing threats from pathogens and insect pests, climate related production shocks, and increasing market competition from foreign imports. Most of the Florida growers believe that labor shortages are the biggest challenge for tomato production, followed by inclement weather conditions. As mentioned earlier, labor shortages during tomato harvesting season and pest and disease infestations due to typical Florida climatic conditions have created difficult production challenges for Florida growers. Unfair trade pressure, where Mexico is dumping produce below the reference price, is another important problem for Florida produce industries. After the implementation of NAFTA, the number of tomato growers in Florida reduced from 300 to 25. Fresh tomato exports from Florida to Mexico during the winter are minimal. Hence, according to the growers, the tomato industry is facing one-sided trade. In addition, the value of the Mexican peso is lower than that of the U.S. dollar (as of 25 July 2020, 1 U.S. dollar = 22.28 Mexican pesos). Hence, the Mexican farmers are getting higher profit margins from exporting their produce to the U.S. rather than selling them in their domestic market. Large U.S. producers are also investing in Mexico to produce fresh fruits and vegetables at lower input costs compared to the U.S. Therefore, not all of the farmers are struggling equally due to strict trade regulations.

International trade also increased the introduction of invasive exotic pests into Florida. In late 2019, brown rugose virus was found in tomatoes in Florida that were imported from Mexico. In June 2018, oriental fruit flies (*Bactrocera dorsalis*) were detected in South Florida, which triggered the quarantining of all sales from the region and thus resulted in considerable revenue losses. The new trade regulations put in place therefore call for more stringent quarantine standards on fresh produce imports.

Despite these challenges, the Florida tomato industry is remarkably striving to stay sustainable by implementing best management practices to prevent or minimize environmental impacts. The majority of the growers are adopting fair food production certificates, which provide better wages and working conditions to workers, and education to the farmworkers' families. The Florida tomato industry is not only looking to achieve production goals, but also improve the social lives of farmworkers and laborers. While a limited number of large growers have developed their own proprietary heat-resistant varieties, most of the remaining farmers have widely adapted publicly available tomato varieties. The development of pest-resistant varieties suitable for Florida's agro-climatic conditions will further help the farmers to minimize input costs and improve the environmental sustainability by reducing pesticide applications. Affordable protected agriculture structures, with some recommended structural modifications for the tropical climate, have the potential to increase productivity and eventually minimize the cost of production. The enforcement of strict laws are also very important to maintain the produce quality and to reduce unfair trade pressure. The application of precision agriculture tools, artificial intelligence, automation, and agricultural robots will allow for increased efficiency and cost reductions in different segments of the produce industry.

Besides adapting to on-farm environmental, economic, labor, and technological issues, Florida tomato growers need to explore more robust and innovative marketing strategies. First, large Florida growers are already looking to diversify their produce streams through market integration, innovative packaging, and directly selling to food services and retailers both in and outside of Florida. Certain small growers, particularly those operating near large metropolitan areas such as Miami, Tampa, and Orlando, are also selling directly to large retail networks. In fact, the COVID-19 pandemic was an era of reckoning for some of the large Florida growers who could not get their shipments out of farms and packing houses for weeks, and lost some in the process. On the contrary, small growers who had direct relationships with retailers had more stable and faster shipments. Going forward, Florida farmers may cope with increasing foreign competition in the traditional fresh tomato market by continuing to innovate and create new supply streams.

Second, Florida growers have significantly improved their performance in both environmental stewardship and ethically responsible labor treatment. There is ample evidence that consumers are willing to reward producers for sustainable and fair food production with premium prices. However, in order for this to materialize, there is a real need for the two-way flow of information between producers and consumers. The logical first step for this information flow is to have an affordable and credible system for the measurement, monitoring, and third-party certification of sustainability performance at the farm level. The fresh produce certification landscape has multiple entities, each certifying a single aspect of sustainability, e.g., environmental stewardship, organic production, fair food, food safety, Florida grown, etc. In order for farmers to take advantage of multiple produce quality attributes, they have to contract multiple certifying agencies. In particular, small growers find having to deal with multiple certification agencies confusing, cost-inefficient, and cumbersome. On the other hand, certification agencies express that each type of certification is unique and complex. Stacking multiple attributes into one-stop certification could compromise standards and certification credibility. However, some level of compromise between producers, consumers, and certifying agencies will be necessary for future certification efforts.

Author Contributions: Conceptualization, S.C. and M.B.; methodology: S.C. and M.B.; data and graph preparation: S.C.; original draft writing: S.C. and M.B.; reviewing, editing, and suggestions: S.C., M.B., K.G.S. and K.J.; funding acquisition and resources: M.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research was made possible by support from the Walmart Foundation.

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Institutional Review Board of Florida International University (protocol code IRB-19-0251 and date of approval 21 May 2019).

Informed Consent Statement: Informed consent was obtained from all the survey participants involved in the study.

Data Availability Statement: The primary survey data is available upon request. Secondary data used in this study are available from the following sources: FAO data: http://www.fao.org/faostat/en/#data/QC (accessed on 22 January 2021); USDA-AMS data: https://www.ams.usda.gov/market-news/custom-reports (accessed on 7 June 2019); USDA-ERS: https://www.ers.usda.gov/data-products/vegetables-and-pulses-data/vegetables-and-pulses-yearbook-tables/#Supply%20and%20Utilization:%20Fresh%20Market (accessed on 12 October 2019); USBLS: https://www.bls.gov/charts/consumer-price-index/consumer-price-index-average-price-data.htm (accessed on 14 September 2020); USDA-NASS: https://usda.library.cornell.edu/concern/publications/02870v86p?locale=en (accessed on 30 January 2019).

Acknowledgments: The finding, conclusions, and recommendations presented in this paper are those of researchers alone and do not necessarily reflect the opinions of the Walmart Foundation. This is contribution number 1015 from the Southeast Environmental Research Center in the Institute of Environment at Florida International University.

Conflicts of Interest: The authors declare no conflict of interest.

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