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Economic Drivers of Food Loss at the Farm and Pre-Retail Sectors: A Look at the Produce Supply Chain in the United States

Travis Minor, Gregory Astill, Sharon Raszap Skorbiansky, Suzanne Thornsbury, Jean Buzby, Claudia Hitaj, Linda Kantor, Fred Kuchler, Brenna Ellison, Ashok Mishra, Tim Richards, Brian Roe, and Norbert Wilson

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Abstract

This report explores economic drivers of fresh-produce (i.e., fruits and vegetables) loss on the farm and in pre-retail sectors. Price volatility, labor costs and availability, supply chain constraints, retail and consumer quality standards, contract incentives, and existing policy are identified as factors influencing food loss on farms and in distribution channels. To be successful, efforts to mitigate food loss by recovering or recycling food must have viable markets and demonstrate their economic value to growers.

Keywords: food loss, food waste, fruit, vegetable, farm income, produce

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A report summary from the Economic Research Service January 2020

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What Is the Issue?

The U.S. Department of Agriculture estimates the value of uneaten food at the retail and consumer levels at around $161.6 billion annually. While a considerable number of studies have examined this type of food loss, few have analyzed the economic factors that result in loss of food on farms and in distribution channels. This study provides an overview of the drivers of food loss on the farm and other pre-retail sectors with a focus on economic incentives that underlie the way fresh foods are grown, processed, and marketed in the United States. Food loss as it relates to fresh fruits and vegetables is of particular interest because these foods are highly perishable and important to diet quality.

What Did the Study Find?

The balancing of expected costs, revenues, and risks from the sale of produce by growers and distributors plays a substantial role in what is often described as "loss" at the pre-retail level in the produce supply chain. Examples of factors influencing food loss include:

- Price volatility—Prices of fresh produce are volatile. When prices fall below the cost it would take to get additional produce to market, growers may not advance produce through the supply chain because doing so becomes unprofitable. When prices rise, growers harvest more intensively (either by hiring more labor or by lowering product thresholds), and may have the incentive to send lower-cosmetic-quality product to market, which can then be subject to increased loss further down the supply chain.
- Labor costs and availability—Labor, particularly harvest labor, constitutes a relatively high share of the cost of growing and marketing fresh produce. Rising wages and labor availability often combine to increase the costs to harvest a field, leading growers to sometimes abandon the crop before harvest and make numerous other production and marketing decisions that directly impact levels of food loss.

- Supply-chain factors—Investments in infrastructure for produce commodities (e.g., vacuum cooling refrigerated-storage facilities) are large, with benefits often shared across multiple growers. Incurring these costs for crops that would otherwise be discarded and would command (at most) a lower price often is not profitable for a single grower.

- Standards and consumer expectations—Produce that does not meet aesthetic or other requirements, at any stage in the supply chain, is likely to be rejected, either by buyers or by final consumers. Growers, shippers, and retailers make decisions about what and when to cull based on perceived consumer preferences; if any of these supply chain stages anticipate a buyer will not accept their produce, the produce will not be harvested or advanced through the supply chain.

- Contracts—Agreed-upon product quality (i.e., contracting) may reduce some of the variability in returns to growers that would otherwise be inherent in produce markets. However, contracts can also contribute to food loss by acting as barriers to entry for growers who are not already included but might seek access for excess product.

- Policy constraints—Policy (at the State, local, or Federal levels) can play a role in supporting food-loss reduction, recovery, and recycling (e.g., tax incentives for donating food); however, some existing policies may unintentionally serve as barriers (e.g., restrictions on gleaning (collection of excess food for the purpose of donation), supply control through private-public marketing orders) or fail to address the underlying causes of loss. Quality standards such as private and public marketing orders may also impact food loss rates.

While estimates exist of the value of uneaten food at the retail and consumer levels, numerous factors (e.g., data availability, coordination across stakeholders) make it difficult to provide consistent, reliable, national estimates of food loss on the farm and at the pre-retail level. Accurately collecting data on national food loss at the farm and pre-retail sectors would constitute a significant investment that is beyond the scope of this study. Opportunities to reduce food losses and improve farm income have begun to emerge. This study's findings suggest that successful efforts to mitigate food loss need to be accessible and profitable to growers to reduce losses in the pre-retail supply chain.

How Was the Study Conducted?

This study provides an economic framework for analyzing drivers of onfarm and pre-retail food loss. It collects and synthesizes information about fruit and vegetable food loss from the farm through the pre-retail supply chain gathered from relevant academic research, unstructured (nonsurvey) input from industry representatives, and growers themselves as well as case studies of specific commodities. Informal conversations with growers and other industry representatives are used to help frame the issue and provide insights about the definition, scope, and challenges surrounding issues of food loss in fresh produce. The study presents case studies of several key commodities (fresh field tomatoes, processing tomatoes, potatoes, strawberries, romaine lettuce, and fresh peaches) and summarizes the findings of a book on the topic titled "The Economics of Food Loss in the Produce Industry."

Economic Drivers of Food Loss at the Farm and Pre-Retail Sectors: A Look at the Produce Supply Chain in the United States

Introduction

Loss of agricultural production destined for food consumption (food loss) in the United States occurs at all levels of the supply chain from farmers to consumers. The U.S. Department of Agriculture's (USDA) Economic Research Service (ERS) placed a value of uneaten food at the retail and consumer levels at around $161.6 billion in 2010 dollars annually in the United States alone (Buzby et al., 2014a). This represents losses of 31 percent of food produced in the United States: 133 billion pounds out of 430 billion pounds. The Food and Agriculture Organization of the United Nations (FAO) estimates that 1.3 billion metric tons (2,866 billion pounds) of food worldwide are produced and not consumed each year, representing approximately one-third of total food production by volume (FAO, 2011). At first glance, reducing or recovering lost food represents a potentially substantial opportunity to improve the efficiency of food production systems due to the implied waste of inputs in production, shipping, and storage.

While a considerable amount of the academic literature has been devoted to understanding how food loss occurs at the consumer and retail levels, relatively little is known about how much, or why, food loss occurs earlier in the supply chain. Most studies of food loss in the United States consider loss occurring at the retail level and consumer level (Buzby et al., 2016; Buzby et al., 2015; Buzby et al., 2009, Muth et al., 2011; Hoover, 2017), or end-use levels (e.g., food that reaches the consumer but is not consumed) of the supply chain (EPA, 2018). However, significant losses occur on farms and in distribution channels before food reaches retail outlets. Fruit and vegetables are especially prone to losses at these stages due to their perishability, importance of product appearance, and fluctuations in prices. Most studies of fruit and vegetable loss have focused on agronomic and technical issues, but much produce is "lost" because farmers and distributors view the produce as unprofitable or excessively risky to move forward. Measures designed to mitigate food loss must take into account these economic factors if they are to succeed.

This study investigates the economic drivers of fruit and vegetable loss on farms and in distribution channels of the supply chain using information gathered from peer-reviewed studies and conversations with experts, policymakers, industry representatives, and growers themselves. The initial investigation identifies commonalities among six produce commodities that are used to develop case studies. This study addresses some of the existing knowledge (and data) gaps by summarizing what is known about the economic drivers of food loss as it applies to onfarm fruit and vegetable production and losses in the pre-retail supply chain. By first examining economic drivers of food loss (price volatility, labor constraints, supply chain rigidities, standards and consumer preferences), the study then explores some potential opportunities for reduction of food loss and opportunities to improve grower income.

Food Loss Defined

Definitions of food loss vary widely by market sector and methodology (e.g., FAO, 2011; ReFED, 2016; Gunders, 2016; WWF, 2017; EPA, 2018). This study adapts one of the most inclusive definitions of food loss. ERS economists define food loss as "…the edible amount of food available for human consumption but is not consumed" (Buzby et al., 2014a). That definition, which originally focused on only retail and consumer losses, is applied to the onfarm and pre-retail losses explored in this report. That is, any edible part of food produced that may be intended for human consumption, but which is not consumed, may be considered food loss at any point in the supply chain. This definition includes food grown to maturity, but not harvested, and left in the field for any reason. Additionally, food harvested, but either eliminated or diverted from the supply chain, perhaps because of size, color, contamination, or shape concerns, is also food loss.

Defining "food waste" is another challenge. Because this study defines food loss broadly, food waste is herein considered a subset of loss, similar to the approach in Buzby et al. (2014a) and FAO (2019). Other studies define waste as an entirely different outcome dependent on where along the supply chain it occurs (EPA, 2018; WWF, 2018) or as separate from loss due to the underlying motivations behind the lost product (Lipinski et al., 2013). This study focuses on the underlying issues and drivers of food loss, rather than distinguishing loss from waste. Therefore, it uses the singular term "food loss," defined broadly to encompass both loss and waste.[1] Equivalently, using the terminology "food loss and waste" would be functionally the same.

[1] For a more detailed discussion of some of the definitions of food loss and waste, see box "Complicating Factors for Understanding Food Loss."

Complicating Factors for Understanding Food Loss

Current understanding of food loss is hampered by a variety of factors (Hanson et al., 2016; Ellison et al., 2019; Minor et al., 2019). First, no singular definition of food loss exists, and because there is no agreed-upon terminology, there is also no universally agreed-upon way to measure losses.

Lack of Consensus

Table B.1 lays out the similarities and differences among some of the major food loss definitions, which largely come from whether inedible portions of food are included, whether waste is a subset of loss, and where waste or loss occurs along the supply chain, from production on the farm to the retail shelf.

Table B.1
Definitions of food loss and waste

Agency	Food loss	Food waste	Does loss include inedible food?	Is waste subset of loss?	Where does waste begin in the supply chain?
USDA, ERS (Buzby et al, 2014a)	The amount of edible food, post-harvest, that is available for human consumption but is not consumed for any reason.	NA[1]	No	Yes	NA
U.S. EPA (2018)	Unused product from the agricultural sector, such as unharvested crops.	Food such as plate waste, spoiled food, or peels and rinds considered inedible.	Yes	No	After the farm level
FAO (2019)	Refers to any food that is lost in the supply chain between the producer and the market.	Refers to the discarding or alternative use of food that is safe and nutritious for human consumption.	No	Yes	After the producer
WWF (2017/18)	Average unharvested weight as a percent of total yield.	Any food that is not used for its intended purpose.	?	No	After the farm level
EU Fusions (2016)	N/A	Food and inedible parts of food removed from the food supply chain.	Yes	Yes	NA
WRI (2016)	Food and/or associated inedible parts removed from the food supply chain.	NA	Yes	Yes	NA

—continue

Table B.1
Definitions of food loss and waste—continued

Agency	Food loss	Food waste	Does loss include inedible food?	Is waste subset of loss?	Where does waste begin in the supply chain?
NRDC (2012)	NA	All edible and inedible parts discarded or wasted.	Yes	NA	NA
ReFED (2016)	… unintended loss of food during harvesting, post-harvest handling, processing, and distribution.	Food grown and produced for human consumption but not eaten.	Yes	Yes	NA

Note: NA = not applicable. ReFED additionally defines "Onfarm loss" as "Food loss that occurs on farms and in packinghouses; distinguished from food waste in landfills because the majority of this loss is tilled into soils as nutrients."

[1]ERS previously defined food waste as "Component of food loss and occurs when an edible item goes unconsumed…"; however, this definition is no longer in use (Buzby et al., 2014).

Sources: See column 1 in table.

Resources spent on competing definitions dividing loss from waste can lead to different assumptions regarding the nature of food loss and can somewhat miss the point, as defining food loss by itself does not lead to a deeper understanding of the issue, its importance, or potential mitigators. "Waste" is further viewed as a pejorative term and linked with finding fault or assigning blame for an outcome (Creamer and Johnson, 2018). The table shows that some agencies have begun to use this term exclusively. If this causes either producers or consumers to become more defensive about the issue of food loss, it may be more harmful in finding solutions than it is successful at highlighting the problem.

Measurement difficulties and lack of data

Measurement has the potential to clarify and focus efforts. Realizing the importance of comparability across studies, the Food Loss & Waste Protocol (FLWP) released a "Food Loss and Waste (FLW) Accounting and Reporting Standard" to help researchers globally create measurements that are consistent, transparent, and comparable across various dimensions (Hanson et al., 2016). The report simply defines FLW as a combination of what is lost (edible versus inedible) and its (unintended) destination. Destination is important because it reveals that diversion of food, even if it is not able to be quantified, can be ranked from highest to least priority, the origins of which can be traced back to EPA and USDA's Food Recovery Hierarchy (EPA, 2017).

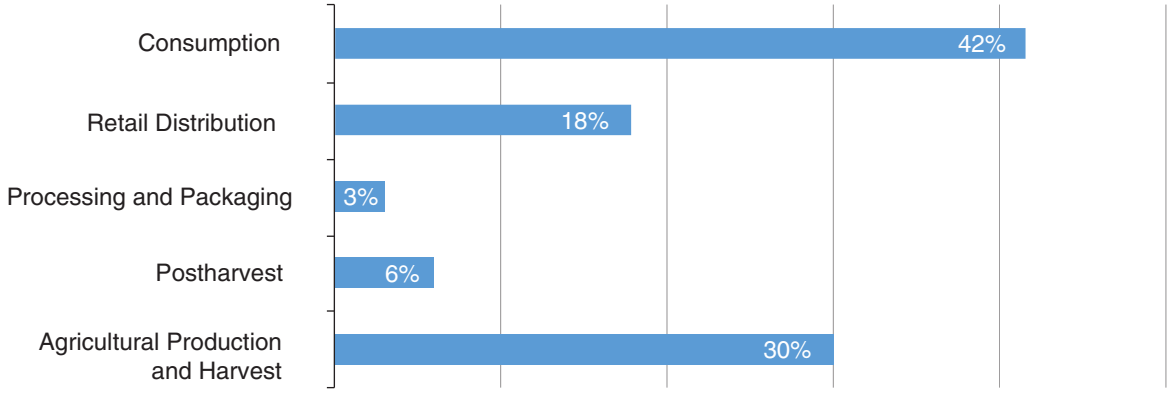
Large-scale, nationally representative surveys of food loss are relatively rare and extremely expensive. In lieu of this, many researchers rely on small-scale, indepth studies of food loss on a particular commodity or region (WWF, 2018). This type of analysis sheds light on the individual instances studied and may help to inform the larger conversation around food loss generally. However, without some common denominator, it is nearly impossible to tell if the estimates from one study are comparable to those of another, are representative of a larger geographic area, or are representative of a longer timeframe.

Why Fruits and Vegetables?

This study analyzes loss in fruit and vegetable markets for two reasons. First, due to their extreme perishability and high levels of consumption, fruits and vegetables are a leading contributor to food loss nationwide (FAO, 2011; Lipinski et al., 2013). ERS estimates that fruits and vegetables (fresh and processed) account for approximately one-third of total U.S. food losses at the retail and consumer levels by weight (Buzby et al., 2014a).[2] Because fruits and vegetables provide some of the more difficult challenges to overcome in their supply chain (i.e., high perishability, short shelf life, susceptibility to bruising), insights from this market could potentially be adapted to less perishable food products.[3]

Second, although losses at the consumer and retail level remain important, some studies suggest that losses from the farm to the pre-retail supply chain represent about half of total fruit and vegetable losses, even in industrialized countries (FAO, 2011). Estimates for North America suggest that nearly 40 percent of losses in fruits and vegetables throughout the supply chain occur prior to the retail or consumer stage, with the largest portion in this early supply chain occurring at the field level (fig. 1) (see FAO, 2011; Hodges et al., 2011; Gunders, 2012; Porat et al., 2018; WWF, 2018).

Figure 1
Estimated food loss for fruits and vegetables in North America throughout the supply chain



Note: Numbers do not add to 100 due to rounding. Product loss is estimated by weight.
Source: USDA, Economic Research Service using data from United Nations Foreign Agriculture Organization, 2011.

An examination of drivers of loss in the upstream U.S. supply chain yields findings that may be applicable to similarly industrialized countries but could be especially helpful in furthering the understanding of food loss in developing countries, where it is estimated that more of the losses occur earlier in the supply chain (FAO, 2011).[4]

[2] By value, this group accounts for roughly the same percentage of loss; however, by calories, fruits and vegetables account for less than 10 percent of total estimated losses, with fats and oils, sugars and sweeteners, and grains making up nearly three-quarters of total losses (Buzby et al., 2014a).

[3] Lessons may run the other way as well, where less perishable food supply chains provide insights on how to reduce food loss in the perishable food chains. Where progress from other supply chains has been gained, this study incorporates those ideas into the understanding of the commodities and issues discussed.

[4] There are also other issues driving food loss in developing countries that the U.S food supply has already addressed, such as lack of infrastructure and unreliable storage (Kitinoja et al., 2011; Kumar and Kalita, 2017).

Drivers of Food Loss and Barriers to Recovery

Compared with efforts to measure food loss in the United States (e.g., FAO, 2011; Buzby et al., 2014a; Buzby et al., 2015; Stenmarck et al., 2016; WWF, 2017, FAO 2018), relatively less attention has been given to identifying the causes of food loss, particularly at earlier stages of the supply chain (Canali et al., 2014; Gunders, 2017; WWF, 2018). If growers and processors maximize profit, one may assume that food loss occurs because eliminating loss is not economically sound under current market conditions.

Often, consumers conceive of the fresh-produce supply chain as seamlessly moving from "farm to fork." The reality is much more complex. Supply chains are complicated, with products moving rapidly across the globe. Produce can be sold and resold, packed and repacked, before reaching the final consumer. In addition, supply chains evolve as technology changes. Moving highly perishable fresh produce from the farm to the consumer often involves the use of advanced technologies for vacuum cooling, packaging, refrigerated trucking and storage, and other infrastructure to maintain product quality and marketability (Minor et al., 2019b).[5]

Agricultural production of fruits and vegetables is inherently risky, as produce in the field and in orchards is exposed to multiple pressures from weather and pests/diseases. Yield and quality change by year and region, depending in part on factors outside of a grower's control. The same planted area may exceed expected yield in one year under ideal conditions and produce a shortfall the next year under less than ideal conditions. This inherent variability may explain occasional food losses, as growers may overplant as part of a risk management strategy to combat uncertainty in the field (see box "Case Study Analysis" for a brief overview of the differences observed in the markets studies for this report; the commonalities between markets generated the drivers of food loss explored later in this study).

Price Volatility

A primary market factor driving food loss is the prevailing market price relative to costs. Produce markets are extremely volatile. Because fresh produce is inelastic in demand (changes in prices often do not drastically affect the consumer's purchase choice), changes in the supply cause prices to fluctuate rapidly (Andreyeva et al., 2010; Weatherspoon et al., 2013). In most cases, U.S. produce markets are highly integrated with global partners (or competitors). Prices fluctuate daily and can often cause the value of edible product to drop below the marginal cost of production, which in turn means that production is simply not economically viable. Depending on where and when the price fluctuations occur, produce could be left in the field, discarded at a packing shed, or dumped from the back of a truck (De Gorter, 2014).

Prices vary not only from year to year but within a given growing season. Some price fluctuations are relatively predictable. For example, prices often increase later in the season as total production begins to decline, though exceptions occur. Others price fluctuations are more idiosyncratic, and thus harder to incorporate into expectations (see box "Weather, Disease, and Pests as Sources of Food Loss" for more discussion on the effects of weather, disease, and pests on price variability).

[5] Some factors will matter more for certain commodities. For example, commodities such as apples or potatoes, which can be stored over a longer time period, will have less rigidity in their supply chain constraints. Therefore, while this study attempts to cover fruits and vegetables as a whole, some economic drivers will impact certain markets more than others. Similarly, some solutions for reducing food loss may work better in certain markets than in others.

Case Study Analysis

To gain a first-hand understanding of factors driving food loss at the farm level, this study examined the supply chain in a variety of produce industries. These case studies provide anecdotal evidence on food loss. Commonalities amongst industries led to a discussion of drivers and potential solutions, but collected here are some of the more specific findings in each commodity market.

Field tomatoes—Mature green tomatoes are hand-harvested while ripe but still green and later undergo treatment to produce the familiar red color. The supply chain is complicated, and one firm can perform many roles (grower, packer, storage and gassing facility operators, re-packer, fresh-cut processor, or transporter), which facilitates coordination and reduces losses. Two key factors are reported as drivers of loss—the market and the natural environment. These factors are interrelated: environmental events can affect price, and market conditions impact the degree of damage from environmental factors that buyers will accept.

Processing tomatoes—Relative to the fresh produce industry, the processing industry is highly efficient. Processing tomatoes are machine-harvested ripe and delivered for immediate use at a processing plant; additionally, processing tomatoes do not face the strict aesthetic standards that contribute to losses in fresh markets. Because losses are relatively low and less frequent, it is difficult to find secondary markets for any leftover product, but this may not be necessary as the product is more storable than fresh commodities.

Potatoes—Potatoes are mechanically harvested, and food loss at this stage is minimal, with unwanted potatoes relegated to animal feed. Potatoes are rarely re-packed and tend to move directly from the packing shed to retail or foodservice distribution centers. Therefore, fresh potatoes tend to experience much less loss due to structural issues in the supply chain than other fresh commodities. Technological developments both from varietal development and production techniques have also resulted in higher yields.

Strawberries—This delicate fruit, which is available year round, is currently hand-picked and is susceptible to plant diseases, insect damage, and competition with weeds for nutrients, water, and light, as well as market fluctuations. The supply chain of strawberry production reveals multiple points where food loss can occur. After fruiting, growers make repeated decisions to harvest fields depending on maturation, quality, and price of fruit and labor availability. In addition, growers may decide to leave product in the field or mow over the field in response to changing market conditions.

Romaine lettuce—Because the heads of romaine are more open than lettuce varieties that produce a closed head, there is more outer leaf trim associated with harvesting of romaine lettuce, contributing to higher estimated levels of food loss. As growers produce more hearts and other value-added preparations of romaine lettuce to meet evolving consumer demands, more outer leaves are trimmed and left in the field. Currently, that trim is plowed under at the end of the growing season to enrich the soil for future plantings, as an effective means of collecting and/or redistributing product trim has not been identified.

Peaches—Thinning and pruning minimize the need to reject peaches at a later stage by increasing the size and quality of peaches produced. Pruning also affects harvest labor, since lower tree heights enable the peaches to be harvested from the ground or with very short ladders.

Weather, Disease, and Pests as Sources of Food Loss

Domestic pest and weather events affect produce prices, quality of the produce, and risk management needs throughout the supply chain, with unfavorable production situations limiting supply and increasing prices. The number one issue from the natural environment that farmers in the case studies described as impacting food loss was weather, specifically unpredictable weather. The main weather-based drivers in food loss described in the case studies include temperature (both too hot and too cold), precipitation and moisture (too much and too little), and excessive sun damage.

High temperatures may affect harvesting decisions, particularly given that California, Arizona, and Florida temperatures might exceed 100 degrees during harvest. Unseasonable temperatures can also influence how and when a plant matures. Growers also reported how temperature could cause too many commodities to ripen at the same time, making it difficult to harvest them (due to labor constraints) and generating a surplus for the market.

Food loss is also driven by too much or too little moisture, including periods of drought or excessive rain and damage from too much dew. Beyond weather, growers also reported pests and disease as environmental factors that drive loss. And while a significant investment has been made on multiple fronts to reduce pest and disease damage, these sources of loss still represent one of the most salient drivers of loss to a grower. As with market fluctuations, growers invest a great deal of effort in trying to mitigate food loss due to environmental impact, including techniques to carefully control soil nutrients and crop irrigation in arid settings. Even for veteran growers, however, managing environmental factors to reduce loss can feel like more of an art than a science (Baker et al., 2019).

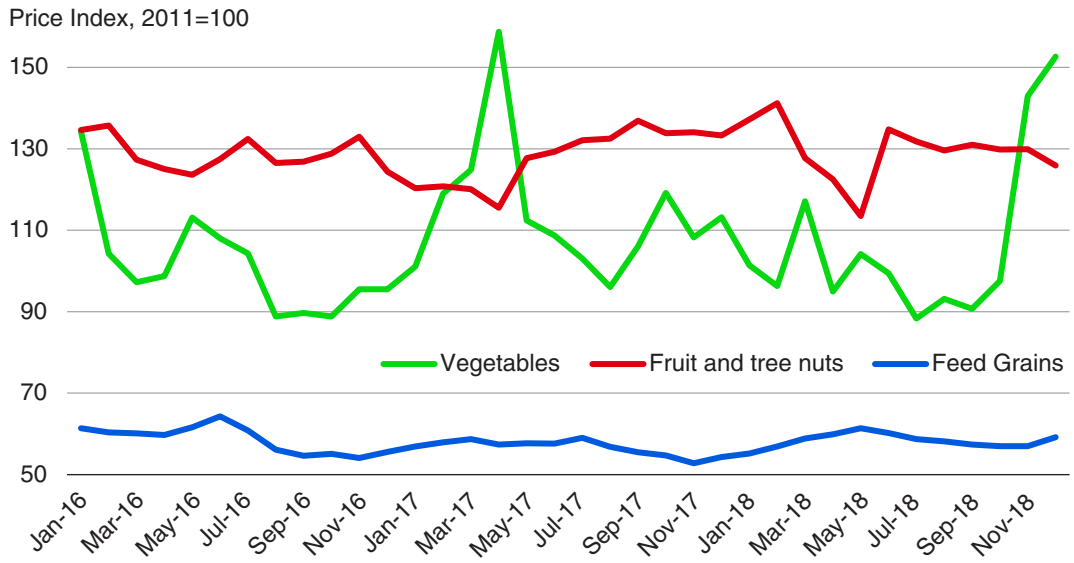
In a recent example, in the early months of 2017, heavy rains in California delayed the harvest of numerous crops. Because of the heavy rainfall, lettuce fields and other fields in the vicinity flooded. This delayed the planting, harvest, and shipment of the crop in California, the leading U.S. producer of many fresh commodities. This delay created a shortage in the retail space for lettuce, which consumers are accustomed to purchasing year-round, and created a spike in both the wholesale and retail price of most lettuces (Parr et al., 2018). Growers across the country scrambled to harvest as much product as they possibly could. Labor that might not have been destined for lettuce harvesting was diverted to lettuce harvesting as growers attempted to fill the shortage and take advantage of the historically high prices. In spring 2017, it is unlikely that any marketable lettuces were left untouched around the country for those few months when California harvests were delayed (Astill and Minor, 2019).

Finally, moving production to controlled environments, such as greenhouses or vertical farming concepts, has the potential to reduce food waste by minimizing environmental exposure that can create cosmetic imperfections. These production systems also allow production schedules to synchronize to the timing of typical consumer demand patterns rather than to favorable weather patterns, which may also reduce waste through closer alignment of the timing of the demand and supply of perishable produce.

The market price directly influences the cost-benefit analysis of harvest (as well as the other costs of production) or, for some commodities, another harvest.[6] The expected market price must cover the costs of picking, hauling, and packing before a worker enters the field. With a low market price, growers might determine that they actually maximize their returns by not harvesting a particular field (Baker et al., 2019). If the price drops, growers have less of an incentive to hire harvest crews; pay for packing, shipping, and cooling of product; etc., and they may leave more product behind than in a normal market, raising observable food loss (Canali et al., 2014; Dunning et al., 2019; Baker et al., 2019; Minor et al., 2019b). Food loss via volatile prices can simply be driven by additional supply, cases in which there is a smaller market for even perfect produce may result in losses in the field as only the top quality produce is harvested. Other situations in which it may no longer be economical for any further harvest to occur, regardless of the product quality still left in the field, include declines in demand, news of a food safety event, or unusually high yields.

Figure 2 illustrates the price variability inherent in fruit and vegetable markets over time. Because these values are indexed for all fruit and vegetable markets, they are less volatile on average than a single market may be. This means that growers of a particular commodity may be faced with even more volatility than is pictured here in the aggregate.[7]

Figure 2
Price volatility in fruit and vegetable markets (compared to feed grain markets)



Source: USDA, Economic Research Service using data from USDA, National Agricultural Statistics Service.

Growers make economic decisions to generate profits, which often means maintaining a strong reputation for quality product. This profit discipline means that destroying edible production is sometimes rational (Richards and Mishra, 2019). For example, in the case of a rapidly maturing crop, like strawberries, if the market price falls at the height of the season, some growers may choose to plow

[6] Some commodities, like tomatoes, may be picked multiple times in a single season, and each harvest decision depends on the cost of inputs into another harvest and the prevailing market price. Dunning et al. (2019) explicitly examine the relationship between an additional harvest and farm profitability. They show that for some commodities, under certain conditions additional harvest may improve profitability, while for others it may not, highlighting the variability of food loss across commodities and growing conditions.

[7] Price spikes for vegetables in March 2017 were related to flooding in California (Parr et al., 2018 and 2019a). Falling prices for fruits in May 2018 were largely due to increased production of noncitrus fruits and tree nuts (Perez and Minor, 2018).

rather than harvest (Hsu-Flanders et al., 2019). While this could benefit individual producers, some edible produce will be lost.

Acceptance levels of quality standards are also flexible for crops that mature quickly, are highly perishable, and are subject to rapid price changes. That is, acceptable quality thresholds may be relaxed by private industry when fresh produce is in short supply and prices are higher.8 Often informally communicated to harvest crews in real time, higher prices due to a short crop may result in less product left in the field or culled during packing and sorting. High market prices may also stimulate additional harvest passes for crops, further decreasing usable product left unharvested.

Price shocks in fresh produce markets are often difficult or impossible to anticipate, particularly in cases where growers sell into national or global markets.[9] Despite these challenges, growers attempt to predict market conditions when making planting decisions and then try to adjust to market volatility in real time. Ultimately, however, because market prices are typically beyond the control of any single producer, growing fresh produce remains a highly speculative and risky venture (Baker et al., 2019).

Labor Costs and Availability

Food loss literature also cites the input cost and availability of labor as a significant factor influencing produce losses (Baker et al., 2019; Astill and Minor, 2019; Hsu-Flanders et al., 2019; WWF, 2018). Labor demand can increase during the season depending on the types of other crops coming to maturity in an area. For example, tomatoes or peppers can be picked 6-8 times per season as fruit ripens to the optimal stage. However, harvesting fresh produce is costly and relies on the availability of manual labor. Growers calculate whether the incremental revenue from another harvest will cover the associated costs and may decide to leave some produce in the field when labor costs rise and/or anticipated harvest is relatively small.

Indeed, many fresh produce commodities are harvested exclusively by hand. For example, with leafy greens, the harvester makes a single cut just above the ground to release the head from the soil. The head is then trimmed of excess leaves with one or two more cuts and packed. This whole process is done very quickly; a matter of seconds from the first cut to being packed. Workers are highly trained to make sure the product meets buyer specifications, so it is both attractive and appealing to retail consumers. Workers are not explicitly trained to minimize product loss as a primary outcome. That is, the goal of harvesting is not to capture all of the edible product that could possibly survive transportation and storage because this is not what buyers and, ultimately, consumers are interested in purchasing (Astill and Minor, 2019).[10]

Rising labor costs shift the cost-benefit analysis of harvesting decisions, indirectly driving increases in food loss (Zahniser et al., 2018). For fresh produce, much of the additional cost of recovery is related to the harvesting itself, which leaves the growers vulnerable to fluctuating labor costs. Production costs vary depending on the type of crop, labor, and harvest activities. Table 1 summarizes average production costs by category for selected commodities with estimated budgets that

[8] These thresholds relate to a variety of factors including shape, size, and look of the product (USDA, AMS, 2019a and 2019b). For example, a buyer may begin to accept U.S. grade No. 2s, rather than only grade No. 1s, in a time of tight supply. These are not food safety thresholds, and thus the shift in grade should not affect the food safety quality of the produce.

[9] A grower selling locally may have a good idea of the other factors affecting price (neighboring production, weather, etc.), but these factors become much more difficult to predict and incorporate effectively on a national or global scale.

[10] For more information, see the section on standards and consumer expectations.

separately list labor costs.[11] Among these crops, the share of labor costs as a function of total (all reported) costs is greatest for peaches (20 percent), tomatoes (15 percent), peppers and potatoes (7 percent), and carrots, lettuce, and spinach (about 4-5 percent). Overall, labor accounts for about 10 percent of the total production costs for the fresh produce commodities listed. When labor is considered with machinery, packing materials, harvest, and tools, etc., that percentage jumps to 36 percent of total costs.[12] At the margin, any increase in labor costs could lead a grower to decide to leave product in the field, dependent on the price the product will fetch on the market (Hitaj et al., 2019).

Table 1
Average total production costs by category for selected produce crops (2013 dollars)

Crops	Labor	Harvest ($)	Total ($)	Average labor share ($)	Average labor and harvest share ($)
Lettuce	427	3,982	9,195	4.5	47.9
Fresh tomatoes	1,560	2,724	9,981	15.3	42.9
Spinach	125	988	2,930	4.0	38.0
Peaches	1,171	841	5,557	20.1	36.2
Peppers	719	2,205	10,539	7.3	27.7
Carrots	97	543	2,359	4.5	27.1
Potatoes	217	374	3,071	6.8	19.2
Average	617	1,665	6,233	9.9	36.6

Source: Enterprise budgets used by USDA, Economic Research Service in the Regional Environment and Agriculture Programming (REAP) model, originally documented by Johansson et al. (2007). Only enterprise budgets with a separate cost category for labor were included, and the average labor share of total costs is included. Budgets differ in how they allocate costs across categories. The average total is not equal to the sum of the subcategory averages. Costs presented are average total costs per activity, measured at the operation level.

Like the steadily rising price of onfarm labor (Zahniser et al., 2018), labor shortages at critical times can lead growers to leave product in the field or to delay harvesting (Baker et al., 2019; Dunning et al., 2019). Strawberry growers in California reported that labor is the biggest challenge to the industry (Guthman, 2017). Growers demand some amount of labor throughout the production period, but at harvest, growers have continuous, time sensitive, and often greater, demand for labor. If labor is not readily available or the price of labor is too high relative to the return on harvest, growers may leave the field unharvested. Labor shortages often lead growers to abandon fields, sometimes over multiple years. Sometimes growers decide to sacrifice a portion of the field to ensure that the highest quality product makes it to market.

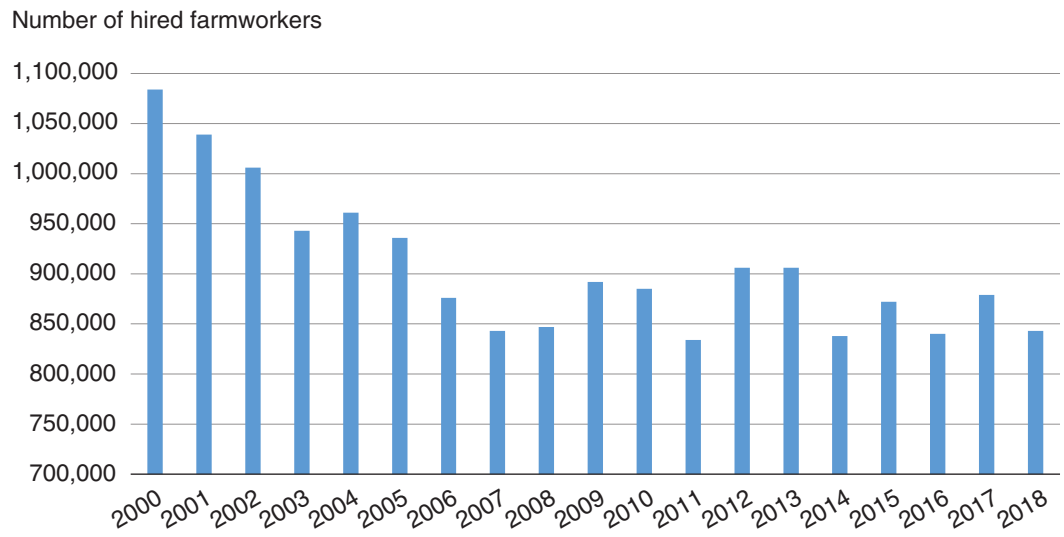
Demand for hired farmworkers has fluctuated over time (fig. 3). The number of workers fell steadily from over 1 million in 2000 to just under 850,000 in 2007. Since 2007, the number of hired workers has remained relatively stable, with no sharp or sustained declines.[13]

[11] Extension crop production budgets guide farmers in the type and amount of expenses they can expect to incur in establishing a new crop or producing from an established crop. The budgets do not follow a set format, and some include more detailed break-outs of cost categories than others.

[12] Because budgets differ in their reporting, we are unable to definitively conclude that all labor is separate from the harvest category in these calculations. Therefore, the combination of the harvest and labor category may be the most illustrative of comparisons between commodities, as it is likely to encapsulate many of the costs of getting product out of the field.

[13] Over this same time horizon, total U.S. production of vegetables has fallen from 40.5 billion pounds in 2000 to 35.9 billion pounds in 2018 (Parr et al., 2019b); similarly, U.S. production of fruits has fallen from 74.4 billion pounds in 2000 to 58.4 billion pounds in 2018 (Perez, 2018).

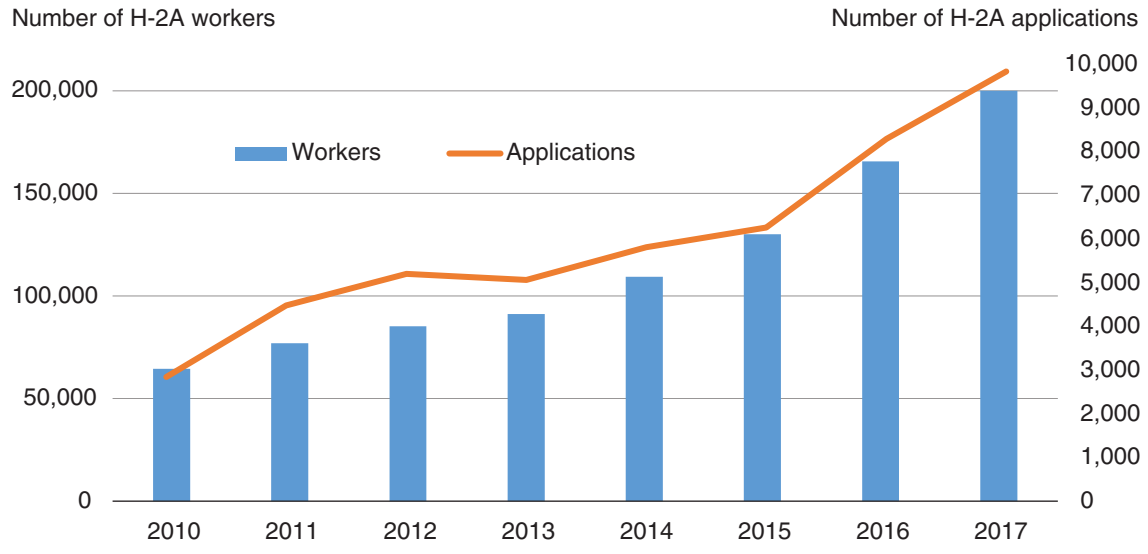
Figure 3
U.S. hired farmworkers for all crops



Source: USDA, Economic Research Service using data from USDA, National Agricultural Statistics Service (NASS). Numbers presented are from annual July estimates of the number of workers. Because farm work is highly seasonal, NASS presents estimates four times throughout the year. All estimates show a similar decline over time; we chose to illustrate the July numbers as they may best capture the beginning of the harvest season for some produce.

To combat the loss in more traditional (migrant) labor sources, many growers have turned to alternative programs and recruitment strategies (Zahniser et al., 2018). For example, growers are increasingly reliant on obtaining guest workers through the H-2A visa program or through farm labor contractors (FLCs). Since 2010, the number of H-2A approved workers and applications across all agricultural industries (not only fresh produce) has grown by 276 percent (fig. 4).

Figure 4
H-2A workers and applications in U.S. agriculture



Source: USDA, Economic Research Service using data from U.S. Department of Labor, Office of Foreign Labor Certification.

Harvesting produce, including minimizing damage and recognizing quality differences, requires skill and experience. In addition to the challenges posed by labor scarcity, the class of qualified laborers is "aging out" at a faster pace than the influx of new, and younger, laborers. Demographic shifts such as lower birth rates in Mexico, a major source of U.S. farm labor, is curtailing the supply of laborers (Taylor et al., 2012; Charlton and Taylor, 2013; Fan et al. 2015; Zahniser et al., 2018). Further, improved economic conditions and education in Mexico and the rising cost of housing in primary growing regions have hampered the supply of laborers.

The labor compensation method (piece-rate versus hourly wage) may also affect harvest losses (Hill, 2019; Stevens, 2019). As piece-rate compensation increases with the total amount harvested, workers may rush and harvest all sizes and grades and fail to remove stems or stalks that could puncture other produce.[14] Alternatively, hourly wage compensation provides less incentive for the quantity harvested and may induce workers to pick more carefully. This is often beneficial for plant health and for harvesting produce that makes both size and grade standards, potentially reducing discard rates at the packinghouse while increasing the amount of product left behind in the field (Baker et al., 2019).

Supply Chain

While market fluctuation in the sales price and the price of inputs are often first cited as drivers of food loss, market infrastructure and supply chain rigidities are also contributing factors. However, much of the food loss discussion in the United States ignores the early stages of the fresh food supply chain, from the farm through transportation and processing (Kitinoja et al., 2018). This is partly because some early research suggested that losses are relatively small near the farm stage in developed countries (FAO, 2011) and because losses at these early stages may be less visible to the public than post-consumer waste.[15]

After harvest, the shipping and packing process can play a pivotal role in produce being left behind or culled from the marketplace. Because of the extreme perishability and sensitive nature of many produce crops, the fresh produce industry has invested heavily in streamlining the supply chain to minimize post-harvest loss. Many commodities are packed fresh from the field and immediately go into vacuum cooling or other controlled-environment storage within hours (Astill and Minor, 2019). Some commodities are not field packed but are instead packed in large open-air bins suitable for transport in trucks. Retailers examine produce upon delivery and cull damaged items. Growers and shippers receive frequent feedback and quality assessment from the receiving dock, much of which is passed on by quality supervisors in the form of daily, weekly, and monthly reports. Thus, throughout the supply chain, growers and buyers make frequent decisions about practices that might lower the chance of loss. This is a process of continuous quality improvement.

Throughout the shipping process, maintaining appropriate temperature, carbon dioxide levels, and humidity is important to preserving quality. Loss of quality through mold growth, bruising, or other causes of deterioration can occur during shipping. In these conditions, produce at the bottom of a container can be damaged by the weight of the produce packed on top of it. Picking under-ripe produce helps avoid some of the damage incurred during shipping. In order to harvest the more-ripe produce left behind, this shipping process would have to be adjusted, which would likely mean a substantial investment in infrastructure (Baker et al., 2019). As the container environment is continuously monitored, the problem of quality loss during transportation can be largely attributed to

[14] That is, a piece rate may initially result in more produce taken out of the field but may lead to greater losses further down the supply chain as damaged produce deteriorates more quickly, possibly affecting other produce packed nearby.

[15] Onfarm losses are often plowed under to enhance soil fertility, making them less visible than food rotting in a landfill.

poorly selected product. Because the risk of lost product more often falls back to the grower and not the shipper, growers are careful to select produce that is well suited for the typically long-haul shipments to a final consumer (Hsu-Flanders et al., 2019).

Nevertheless, some loss persists. The cold chain is critical to maintaining quality from the point of harvest to the final consumer.[16] Disruptions in the cold chain (e.g., power failure, faulty equipment) lead to rapid deterioration of quality and food loss. Many larger growers in major production areas have cooling units that cool the product quickly.[17] Any delay in entering the cold chain quickly reduces marketability; consequently, cooling units must be located near central growing regions, if not directly on the farm (Hsu-Flanders et al., 2019).

Due to the high level of investment in infrastructure for a specific commodity market, switching produce to a different outlet is not typically a straightforward process. Some products not sold into the fresh market, such as blueberries and apples, may be easily moved to alternate (albeit typically less valuable) processing markets. Other products, such as fresh tomatoes, do not have these options as standards and varieties vary substantially by intended use (e.g., fresh versus processed end products). Infrastructure investments for produce commodities are substantial, and undertaking these costs for currently lost food, which would command a lower price in alternative markets, often simply does not make economic sense for a single grower.

Standards and Consumer Expectations

Retail specifications, along with grading standards, explicitly state requirements for a product's appearance and other characteristics. Buyers have quality standards for specific reasons, such as food safety considerations or consumer preferences, and will reject a deficient load, resulting in lost profits and loss of reputation (Calvin et al., 2001). The most visible standards related to fresh produce are voluntary standards set by USDA's Agricultural Marketing Service (AMS) in conjunction with the affected industry. According to AMS, "U.S. Grade Standards for vegetables are voluntary and provide the fruit, vegetable, and specialty crop industry with a uniform language for describing the quality and condition of commodities in the marketplace" (USDA, AMS, 2019a) and help provide some stability and solve marketing problems that growers cannot solve individually (USDA, AMS, 2019a and 2019b).[18] AMS also supports marketing orders, which "are industry-driven programs that help fruit, vegetable, and specialty crop producers and handlers achieve marketing success" (USDA, AMS, 2019c), by providing oversight authority on more than 20 individual specialty crop (SC) markets. In addition to setting "mandatory minimum standards on products shipped in order to prevent inferior quality product from depressing the market for the whole crop," marketing orders also "assure customer satisfaction, and drive increasing consumer repurchase" (USDA, AMS, 2017). These sets of standards are meant to provide a common language for producers and buyers to communicate about quality and promote efficiency in marketing and procurement.[19]

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[16] "Cold chain" refers to multiple steps in the harvest and transportation of fresh produce where temperature and other environmental factors are under control to prolong product shelf life. Typically, once a product enters the cold chain, temperature and other environmental factors are maintained as the product changes hands.

[17] For smaller growers, cooling may take place through affiliated packing sheds rather than onfarm. For many fresh produce items, cooling is necessary, not optional, regardless of farm size.

[18] The standards discussed here are outside of those Federal (Astill et al., 2018 and Astill et al., 2019) and buyer-driven (Minor et al., 2019a) food safety requirements, which are discussed more thoroughly in the section "Existing Policy and Unintended Consequences."

[19] Private standards may also exist in these markets, often specific to an individual commodity market (which could be a commodity, region, or a buyer-seller relationship). Private agreements go beyond what is provided by the public standards and may require a higher quality threshold or certification of other practices (e.g., environmental, human rights) not overseen by USDA.

Moving produce through the supply chain includes inspectors, requested by financially interested parties (often marketing orders or other industry representatives), who maintain grades and standards in the industry. Through random and representative sampling, inspectors evaluate the product based on various factors including maturity, appearance, color, shape, size and the presentation of the packaging (USDA, AMS, 2019a and 2019b). Inspectors assess the condition of the product, looking for defects, such as signs of bruises, leaking fruit, mold, decay, or other signs of deterioration. This process generates a score that inspectors use in assigning a grade and determining if specifications have been met. The inspector never makes decisions regarding disposition of the product, but the inspection certificate helps industry members determine value, which can guide disposition decisions. Companies make decisions about quality based on these standards and market conditions, deciding to advance or cull produce accordingly (Hsu-Flanders et al., 2019).

Grades and standards may help to mitigate costs incurred from unsaleable product by stopping the unsaleable product as early in the supply chain as possible. Cosmetic imperfections visible in the field may worsen over time, resulting in unsaleable product after transportation through the supply chain. Mildly decayed or moldy produce, while technically edible, could contaminate nearby product that meets standards, rendering it ultimately unsaleable as well and exacerbating loss. In such cases, moving unsaleable food forward incurs additional labor, transportation, and storage costs, which reduces profit relative to simply abandoning the product in the field, or repurposing it for some other more efficient use (e.g., compost).

While the stated goals of these standards often do not directly address food loss, many of the goals, such as opening products to the largest number of potential markets, may have spillover effects in curbing some loss. More recently, market opportunities provided by Fruit Vegetables and Specialty Crop (FVSC) marketing orders have expanded to include actions on food loss. The Florida Citrus and Idaho-Eastern Oregon Marketing Orders provide specific processing outlets for product that does not meet fresh grade standards. (USDA, AMS, 2019c).

Conversely, grades and standards and consumer preferences prevent some edible product from moving forward in the supply chain because it is deemed unmarketable. For instance, if consumers are unwilling to purchase "ugly fruit" (e.g., an apple with russeting on the skin), retailers are unlikely to accept fruit below a cosmetic threshold that includes the undesirable attribute. The actual quality of fresh produce grown on the farm is uncertain and will fluctuate with many factors outside a grower's control (e.g., weather, disease, and pests). Fresh produce that does not meet aesthetic or other requirements is likely to result in food loss regardless of whether the produce is grown under contract for a restaurant or for sale in a local farmers' market.

Rigid consumer preferences, or at least rigid retailer interpretations of consumer preferences, translated to quality thresholds are cited as a driver of in-field loss for produce (Baker et al., 2019). If growers anticipate customers will not buy produce below a certain standard, the produce will not be harvested. Retailers and consumers are accustomed to uniform, relatively perfect fruits and vegetables. This typically results in cosmetically deformed or misshapen produce and any that are too large or too small being left in the field, despite the fact that they may be nutritionally equivalent to the more uniform fruit and vegetables. This leaves edible food behind that would be satisfactory for consumers who may not require perfect uniformity of produce (Baker et al., 2019).

Contracts

To limit uncertainty associated with produce quality standards and pricing, some markets have incorporated formal contracting into their buying procedure. Growers and buyers of agricultural goods (such as processors or handlers) use agricultural contracts to reduce risk and secure marketing channels for sales of goods outside of traditional spot markets. Produce contracts will most often specify the volume, sales price, and physical quality of the product to be delivered. In this way, contracts help solve the issue of coordination: growers would like to sell all of their output, while buyers would like to purchase the quantity they need. As agricultural contracts continue to increase over time, they may increasingly influence food loss in different market contexts.[20]

Loss rates may differ when buyers and sellers trade produce via contracts. Growers with fixed price contracts or an agreed-upon volume will harvest regardless of the market price since they have a guaranteed contract price and do not have the ability to leave produce in the field if they believe the agreed price was not favorable, ex post. Contracts reduce market-price volatility, compared to spot markets. Marketing contracts can help reduce food loss by coordinating the terms of trade for buyers and sellers. More frequent monitoring reduces the likelihood of food loss due to quality uncertainty. Third-party graders reduce risk within the contract, which reduces the likelihood of food loss due to conflicts over the delivered quality of produce (Skorbiansky and Ellison, 2019). A well written contract includes explicit expectations and standards. Often, contracts may reduce some of thevarability inherent in produce markets, but they would need to be written with food loss in mind to reduce unintended consequences.[21]

Growers and processors may be risk averse, preferring a surplus to a shortage, when they must deliver or have the opportunity to sell a pre-determined volume (Kahneman et al., 1991, De Gorter, 2014). Some contracts severely penalize shortages, whereas a surplus may also be bought by the customer (possibly at a lower price) or sold into secondary channels. Keeping additional product on hand can be a grower's optimal strategy for risk management.

There are a few other situations where contract use could exacerbate food loss. Depending on the value and fragility of relationships, growers may be more likely to overplant, ensuring product they deliver is at or above expectations. Premium schedules, which incentivize off-season production, could shift the distribution of output quality downward, increasing the likelihood of rejected produce. Finally, poorly written contracts may incentivize food loss if there is an opportunity for moral hazard or adverse selection[22] to influence a grower's profits. In addition, poor enforcement of contracted standards could also create losses. Carefully written contracts avoid such issues by providing the necessary incentives or payment schedule to ensure growers invest in producing high-quality output and ensuring buyers adhere to the terms of sale.

[20] Almost 40 percent of the value of U.S. agricultural production in 2008 was grown under contract, compared to 28 percent in 1991 (McDonald and Korb, 2011).

[21] Most current market contracts do not seem to address or acknowledge food loss in any way (McDonald and Korb, 2011).

[22] Moral hazard and adverse selection are two problems that can occur when there is information asymmetry. Moral hazard happens if a grower lacks incentive to protect crops against risk given protection from the consequences (e.g., crop insurance could incentivize growers to take on more risk than necessary (Smith and Goodwin, 1996) and that risk could lead to losses). Adverse selection happens if the growers or buyers have private information about themselves that has not been shared (e.g., growers with private knowledge of poor soil quality may not share this information for fear of losing a contract).

Existing Policy and Unintended Consequences

A single-minded pursuit of any policy goal may lead to unintended consequences, and food loss reductions are no exception. For example, if a policy incentivized growers to send all of their edible produce to a wholesaler, it could result in defective or imperfect produce being thrown out at later points in the supply chain (i.e., at the wholesaler, retailer, or consumer levels). This policy would not actually reduce food loss; rather, it simply shifts the point where the losses occur, likely requiring more investment in ultimately uneaten produce that may end up in a landfill. Such a policy would also prevent growers from plowing under the damaged or cosmetically imperfect produce and fertilizing future crops. The further down the supply chain food is lost, the more resources will have been expended.

Foodborne Illness Outbreaks as a Source of Food Loss

Relatively low-frequency but high-impact events, such as a foodborne illness outbreak linked to a particular crop, were often cited by growers as a potential source of food loss. These events could prove harmful to a market if all consumers quickly stop their purchase of a commodity which is deemed safe, but that information is not able to be quickly and easily passed along to the buyers.

For example, in March 2018, illnesses of *E. coli* O157:H7 began to be identified. The outbreak, which ran until the end of June and affected 36 States, consisted of 210 illnesses and 5 deaths that were linked to romaine lettuce produced in the Yuma growing region of Arizona. In November 2018, another *E. coli* O147:H7 outbreak occurred when 62 individuals were made ill after eating romaine ultimately found to be harvested in central California. During the fall outbreak, FDA first advised consumers to avoid romaine lettuce. Later, the agency revised its advice to avoid romaine from central California.

When each of the outbreaks in 2018 began to gain national attention, growers outside of the implicated area were unable to sell their product through traditional retail channels for a period of time. Some consumers were unwilling to purchase any romaine, even with assurances that the product was not grown in the contaminated region. In the case of the spring 2018 outbreak in Yuma, prices were so low that some California growers found it more cost effective to simply plow their romaine crop under than to harvest, cool, and ship the product. Both outbreaks led to dramatic swings in price that altered growers' decision process about harvesting, labor, and shipping, all of which led to extreme changes in the amount of food loss in the market. A study of a similarly sized outbreak in 2006 shows that consumers largely substituted away from implicated produce items to substitute goods at a similar rate (Arnade et al., 2009). This suggests that while traditional consumers of romaine may have purchased less during the 2018 outbreaks, they likely substituted a different leafy green, creating an ambiguous effect on overall food loss.

Existing policies may also incentivize growers to leave product in the field or exclude it from the early supply chain. Product can also be left unharvested due to food safety risks associated with potential microbial contamination. For example, the Leafy Greens Marketing Agreement (LGMA) mandates a harvest buffer of 3 feet from any signs of animal intrusion and a minimum of 5 feet from the presence of animal feces (CA LGMA, 2019).[23]

Growers harvest all salvageable product possible while reducing the risk of unsafe food entering the marketplace. While it may be technically possible to reduce the amount of product lost at this stage by reducing the harvest buffer zone, it is unlikely to be economically efficient due to potentially severe negative impacts for consumers (e.g., serious foodborne illness or death), does not specify any set harvest interval or buffer zone but suggests "measures reasonably necessary" (Astill et al., 2018) growers, and the industry (e.g., sales loss and liability) (see box "Foodborne Illness Outbreaks as a Source of Food Loss").

Tax policy has implications for food loss at the farm level. For example, donations represent a potential tax savings for many businesses, and some States as well as the Federal Government incentivize farm donations to nonprofit entities (USC, 2011; NGP, 2015). However, many growers may be unaware of these benefits, or because the benefits take the form of income-tax deductions rather than a direct payment of funds, growers may choose not to take them. There are concerns among growers about loss of reputation and liability exposure from a product once it moves forward in the supply chain (Minor et al., 2019b). For example, because growers cannot verify that donated produce will be handled in a safe and secure manner, there is concern that donated food could be implicated in a foodborne illness traced back to a grower's operation. The Bill Emerson Good Samaritan Food Donation Act limits growers' liability (USC, 1996), but producers are still reluctant to let product with their label be at increased risk of a foodborne illness event. Some growers suggest that even having their product labeled at a food bank could potentially damage the brand, suggesting that their produce was of lower quality.[24]

[23] Some growers may quarantine off less (if not formally a part of LGMA) or more depending on the type of animal or severity of the intrusion. The Food Safety Modernization Act's Produce Rule does not specify any set harvest interval or buffer zone but suggests "measures reasonably necessary" (Astill et al., 2018).

[24] It could require additional resources to remove labels or packaging that might identify the grower prior to donation, an investment which would not be recouped.

Potential Solutions

Potential solutions to food loss generally fall into two broad approaches: source reduction and redistribution. The first step on the EPA's food recovery hierarchy is source reduction of surplus food, and some argue that the most efficient means of reducing food loss throughout the supply chain is to identify sources of loss and stop those unproductive areas of production (EPA, 2017). Such preventative actions may include new value-added products from excess or lower grade produce, new efficiencies that reduce harvesting cost and damage to product during harvest, new technologies for preserving the quality of produce while in distribution, retail, or even in consumers' chiller drawers. This type of source reduction has obvious environmental benefits if indeed the losses are avoidable because less land, fertilizers, water, and other inputs are put into produce growth that does not get consumed by people and could also be beneficial to the grower's bottom line, if they were no longer sinking those same costly inputs (plus labor) into the ultimately unsold product. However, difficulties arise around the uncertainty surrounding food production and loss and the risk management strategies employed by producers. As outlined above, the causes of food loss in fresh produce markets in general are volatile, changing from season to season and crop to crop—there could even be no produce lost in some years.

Research into market mechanisms that underlie food loss is growing as policymakers realize the potential opportunity to move toward food security, environmental, and resource-use goals simply by making better use of what is already being grown. Further, researchers are also beginning to understand that alleviating the problem of food loss requires a solution that benefits all parties involved in food recovery (ReFED, 2016; WWF, 2018). In some cases, actions might provide new economic opportunities and stimulate rural development, actions, and ideas explored more fully in the following sections.

Gleaning and Food Donation

Perhaps the most traditional method for collecting and redistributing unsold or unharvested food is gleaning. Gleaning refers to the collection of excess food from farms, other supply chain sectors, or retail sources for the purpose of donation. Gleaning reduces the amount of food loss while also potentially providing produce for people who may be food insecure (i.e., they lack access to enough food to maintain a healthy life). Today, a significant amount of gleaning takes place through a system of donation, generally collected by volunteers who are typically not the beneficiaries, to mitigate food loss while also feeding people in poverty.

Gleaning organizations tend to be united by a common mission, but approaches and organizational structures differ (Gunders, 2017).[25] As of 2019, the National Gleaning Project listed 282 organizations and chapters operating in 45 States, the District of Columbia, and nationally (NGP, 2015). While the list is not exhaustive, it represents the range of gleaning models in the United States.

Commercial farms often have larger volumes of excess produce, so they are better suited for gleaning and donations. Gleaners that partner with commercial growers constitute some of the largest donors to food banks in terms of volume (Vitiello et al., 2013). Coordinating the logistics of harvest and transportation at a single farm is easier than aggregating donations from many sites. In addition to partnering with commercial farms, some high-volume gleaning organizations are harnessing the expertise of farm laborers to harvest excess produce. Some employ low-income farmworkers to glean produce that is distributed through their own programs and local partners.

[25] In fact, gleaning was a priority of USDA Secretary Glickman throughout the 1990s, an interest that stemmed from a 1977 report to Congress (see GAO, 1977).

Because these workers are already trained and guaranteed a wage, they form a reliable and efficient labor pool. However, smaller and volunteer-supported gleaning organizations remain a large part of the food recovery landscape (Feeding America, 2014; NGP, 2017b; Gallagher et al. 2019).

Fresh produce is perishable and often requires cold storage, so gleaners must overcome challenges related to packaging, transportation, and storage. Many gleaning operations operate similar to a small wholesaler, with logistics management and infrastructure development. Management and distribution are coordinated by full-time staff members, in addition to a large volunteer labor base (NGP, 2017a).

Successful gleaning organizations build trust and establish rapport by developing expert agricultural knowledge, maintaining consistent communication with their suppliers, and performing quality work that does not interfere with other farm operations. This helps ensure they avoid posing additional costs to producers. Growers benefit from a set schedule and by having a known and reliable outlet for crops that would otherwise go unharvested. There are reasons growers may benefit from harvesting a crop, even if it would not be marketed. For example, harvesting unmarketable product may help mitigate the risk of disease or encourage continued production.[26] In these instances, maintenance gleaning occurs when a continuously fruiting crop is harvestable that growers do not have the time or labor to manage. For example, if gleaners harvest green beans early in the season, the plants will be available for a subsequent harvest that could provide the producer with additional income. Gleaning can further benefit farmers by reducing the time and monetary costs (e.g., transportation costs and tipping fees) associated with disposing of unmarketable produce that cannot be plowed under, such as orchard crops. Finally, gleaning can yield indirect benefits for a grower by increasing visibility within the community (NGP, 2017a and 2017b).

However, there are numerous barriers to a successful gleaning operation as well. Because most operate as not-for-profit entities and the food recovered is often donated, there is little monetary incentive for growers to participate. In fact, the model is built on largely charitable funding external to the growers, originating from a variety of sources that may or may not be sustainable over time (NGP, 2017a). Additionally, though there are some benefits to the growers through reduced tax liability, removal of unwanted produce, or public service, the direct monetary benefits may not exist at all, while the real (sunk) costs of producing that food remain. Because gleaned produce has left the field, a grower may additionally have to invest in compost or other agricultural inputs, which could have been generated by plowing under the surplus food. For a gleaning operation to be sustainable and successful, it needs to provide value to the consumer (through food donations) as well as to the supplier (the grower) through some demonstrated means.

Food Recovery, Recycling, and Alternative Markets

The persistence of food insecurity in the United States suggests that food recovery may be a potential solution to both food loss and food insecurity. However, perishability, transportation costs, and fragmented infrastructure complicate comprehensive recovery efforts (Buzby et al., 2014b). The number and capacity of food recovery and diversion companies have exploded recently, which may improve landfill diversion rates.[27]

[26] For example, most fruit trees are picked clean annually to encourage the next year's crop, except for citrus and avocados, which can have fruit on the tree for multiple seasons. Additionally, greens, cucumbers, peppers, and tomatoes are kept trimmed or picked to encourage continued production.

[27] Even if some food is diverted or donated, there is still food that never makes it to these secondary outlets. Additionally, there is some concern that factoring these outlets into planting decisions could induce more planting, rather than less. (Gallagher et al., 2019).

Some companies create value-added products out of surplus produce, essentially "recycling" the previously lost produce. For example, Misfit Juicery and Ugly Juice, located in New York and the San Francisco Bay Area, respectively, purchase surplus produce, juice it, then sell the juice directly to consumers or to retail locations. Other companies like Ocado and Rubies in the Rubble sell fruit leather and condiments using surplus produce as a way to combat loss and recover more produce (Gallagher et al. 2019). If food recovery efforts entail lower transaction costs or provide a new use for the previously unused product, they are much more likely to be undertaken by producers as a means of lowering observed food loss.

An additional potential solution to reducing food loss is through secondary markets for excess or cosmetically imperfect produce. Cosmetic and standards issues in produce are challenging to manage, even with alternative markets. Though processing markets for many commodities exist for a lower grade product, market demand may not line up with the supply of damaged produce, which varies over the course of a season.[28] Further, many growers decide prior to the growing season if their product is intended for fresh or processed markets, and they make pre-production decisions, such as variety selection, accordingly. There are other barriers as well. For example, processed produce is more likely to be grown under contract, and many growers are not physically located near the processor, meaning the growers' access may be limited geographically or through market structure (i.e., no contracts). Finally, many commodities, such as tomatoes, have entirely separate markets for fresh and processed varieties. In such cases, because the varieties grown for fresh consumption differ from those grown for canning, it is not feasible for a grower to simply switch from the fresh to processed market.

Several companies have created a model where consumers pay for a subscription service and receive a box of "ugly" produce. Among these companies are Imperfect Produce, Perfectly Imperfect Produce, Hungry Harvest, and Full Harvest, which source below-grade or "ugly" produce that would otherwise have been wasted and direct it to consumers. In a traditional Community Supported Agriculture (CSA) model, farmers are paid 100 percent of the price of the box at the beginning of the season, at the time of year when expenses are high, but revenues are low. This model modifies the traditional CSA by sourcing surplus product from multiple farms (at a significant discount) or retail outlets and consolidating this into a single packaged consumer product, potentially supporting multiple suppliers[29] (see box "Retail Space for Cosmetically Imperfect Produce").

Research shows that the surplus-recovery business model used by these firms can be economically beneficial (Richards and Hamilton, 2018). These technology-based food recovery systems operate by efficiently bridging two-sided markets, in which consumers demand a variety of suppliers, and suppliers demand a large number of consumers. Further, these market intermediaries can work efficiently by creating a previously untapped market for produce sales, likely greater than the opportunities a single grower would have on its own.

In order for these new initiatives to continue to be profitable, there must be some benefit to the farmer, and society more generally. Currently, farmers can receive a tax deduction for charitable donations of excess produce, but these benefits do not exist for food sold to secondary sellers like

[28] Fruit and vegetable processors act much more like a typical food processor, with a steady, contracted supply of inputs. Fresh fruit and vegetable growing, however, is much more seasonal, and food loss (or surplus) that might be sold into these alternative markets is sporadic. This complication in timing makes selling surplus produce into these channels more complicated and not a stable, long-term solution.

[29] With this model, the consumers still pay up front, typically month-to-month or weekly rather than for the whole season. Growers are likely paid more traditionally at a piece rate by the aggregator.

Retail Space for Cosmetically Imperfect Produce

Several grocery stores and larger food retailers have introduced new marketing strategies to market imperfect produce, although the persistence of some of their initiatives is unclear. In 2017, the grocery chain Hannaford began a program called "Misfits," which placed reduced-price produce that was misshaped in visible locations in several stores around the Northeast (Haines, 2017). In 2019, Kroger introduced a line of branded misfit produce called "Pickuliar Picks" in connection with its Zero Hunger, Zero Waste campaign (Rose, 2018). Walmart has launched similar campaigns marketing "ugly" produce incorporating discounted product. Walmart's examples seem more specifically targeted at particular crops, including one for potatoes called "Spuglies" that debuted at 400 stores in Texas in 2016 and a separate campaign for apples called "I'm Perfect" in 2016, which launched at 300 stores in Florida (Haddon, 2016). These initiatives are a part of Walmart's larger effort toward monitoring spoilage in its supply chains. In a slight variation on this model, Daily Table based its business model around creating a low-cost grocery option for community residents without the stigma of receiving free food from a food charity such as a food pantry. Daily Table was founded by a former president of Trader Joe's and operates with support of donors, with a focus on healthy food and community engagement. While many of these initiatives are new, some of the U.S.-based solutions have been in existence for over 70 years. Grocery Outlet, which was founded in 1946 and operates 225 retail stores, sources products that otherwise would be wasted and sells them at a discount.

Internationally, other grocers and cooperatives have made efforts to integrate ugly produce into grocery chains. In France, the chain Intermarche launched a campaign called "Inglorious Fruits and Vegetables." In Portugal, a group of citizens with concerns beyond food loss founded a cooperative called Fruita Feia, or "Ugly Fruit" (Godoy, 2014). The creators of Fuita Feia developed the organization in response to the economic downturn in Western Europe. In general, retailers in Europe have made headway in ugly produce campaigns and food loss mitigation; yet, as with the U.S. examples, the lasting impact that these groups have had on food loss across produce supply chains is unclear. Looking into the future, whether these efforts can significantly reduce food loss is an unanswered question.

Recently, there have been some high profile roll-backs of these programs. Walmart, Whole Foods, and others national retailers have discontinued their blemished fruits and vegetables, citing inconsistent consumer interest. Another cited constraint is the difference between the expected discount by consumers and what is feasible for producers and retailers (Choi and McFetridge, 2019). While the failure of these types of marketing strategies in traditional retail settings calls into question the feasibility of this approach long term, some suggest more consumer education on the value of these products still needs to occur (Gallagher et al., 2019 and Dunning et al., 2019).

Imperfect Produce, even at a steep discount. While this model does provide an outlet for less-than-perfect produce, some critics have questioned the unintended consequences of creating a market for wasted produce that otherwise might have been donated to food banks or sold directly to consumers as part of a traditional CSA program. Additionally, because of the sporadic nature of ugly produce, a steady supply is difficult to guarantee, causing some companies to fill orders with produce from more traditional outlets.

Government and Private Sector Investments To Reduce Food Loss

Because food loss occurs for many reasons, one grower is often unable to conceive of and incorporate a solution on his or her own. Thus, larger entities, such as local, State, and Federal Governments, alongside outside investors have begun to address food loss throughout the supply chain.

USDA's National Institute of Food and Agriculture (NIFA) is funding numerous research projects aimed to curtail food loss. The Cyber-Physical Systems Competitive Grants Program is a joint funding opportunity with the National Science Foundation (NSF) focused on scientific and engineering principles that underpin the integration of cyber and physical elements. Goals for the program include increasing food security through the development of high-output, controlled environment agricultural technologies and systems and more robust agricultural systems in general (NSF, 2019). In addition, grants provided through the Agriculture Economics and Rural Communities and Agriculture and Food Research Initiative with researchers at Arizona State University and the University of Georgia aim to apply machine learning to the food waste supply chain and to understand the effects of food retail density on municipal waste levels (USDA, NIFA 2017 and 2019a).

Additionally, NIFA funds projects that touch on a number of issues related to food loss through the Specialty Crops Research Initiative (SCRI). The SCRI works to address the needs of the specialty crop industry by improving crop characteristics; addressing threats from pests and disease; increasing production efficiency, productivity, and processing; researching and implementing new technology; and developing methods to control food safety hazards (USDA, NIFA, 2019b). Similarly, Value-Added Producer Grants, administered through the USDA's office of Rural Development helps agricultural producers enter into value-added activities related to the processing and marketing of new products, with the goals of generating new products, creating and expanding marketing opportunities, and increasing producer income (USDA RD, 2019). Although food loss is never explicitly stated in the goals of these projects, progress on any one of these topics could help to curb food loss at the producer level or throughout the early supply chain.

USDA's Agricultural Research Service (ARS) also has numerous projects underway that have begun to address food loss specifically for fruit and vegetable markets. The Healthy Processed Foods Research initiative has already begun to bring new products and market access to certain growers. With a stated goal to "Increase the commercial value of plant-based, postharvest waste materials … by reprocessing into healthful food ingredients," this research initiative is designed to use processing technologies to improve grower incomes and total food usage. Findings have improved or identified markets for discarded potato skins, whole grape seed flour, persimmons, and mushrooms (USDA, ARS, 2019a).

In addition, the Produce Safety and Microbiology National Program has many projects underway and completed on the microbial pathogens associated with foodborne illness (USDA, ARS, 2019b). While they may not directly address food loss as a primary goal, any projects that improve safety and marketability of produce have the potential to improve grower income and reduce food lost at the farm or early supply chain.

Another frequently cited factor limiting food recovery, and thus driving food loss, is failure in logistics (Buzby et al., 2014b). Along the supply chain from farms to wholesalers, inventory management errors and unpredictable market shifts contribute to food loss (ReFED, 2016). The manifestations of these challenges include identifying excess food along a supply chain, communicating the avail-

ability of excess food to potential users, and coordinating the transportation of food in a timely and efficient manner. For example, many growers do not realize how much of their food loss can be directed into secondary markets because of failures to communicate loss information along the supply chain. In addition, because of the size of a single farming operation, it may not be feasible to collect such information in a rigorous and systematic way.

Over the past several years, the technology and venture capital worlds have taken an interest in food loss. Logistics software firms are developing solutions to mitigate food loss through better communication by identifying areas for reduction and diversion of unused food. Using their software products, these firms help clients more easily communicate among their units: for example, data sharing between sales and purchasing departments can help avoid over-purchasing of products. One initiative is Meal Connect, sponsored by Feeding America, which serves as a platform to connect food donors with needy food banks and their partners (Feeding America, 2019). Additionally, companies are able to track changes in food loss over time, allowing them to monitor their progress toward sustainability goals and enhance employee and customer engagement (Gallagher et al., 2019).

One startup began as an online marketplace, but after early difficulties, the firm decided to focus more on software and inventory management (Food Cowboy, 2019). This company found that a major impediment was matching supply with demand, as well as providing transportation for pickup and delivery. By working on better inventory management systems, in concert with purchasing departments, the company was able to implement scalable plans that increased communication, built data, and found alternative buyers. Another group of startups works on reducing spoilage along the supply chain. For example, one firm has released a proprietary coating for avocados and other fruit that slows ripening (McShane, 2019). Its product acts to slow water loss and oxidation, thus extending shelf-life for retailers and consumers. Similarly, firms are producing an edible biopolymer coating to extend produce shelf-life and support quality through the supply chain (Yousuf et al., 2018). USDA, ARS, too, has multiple projects aimed at extending product life. The Genetic Improvement of Fruits and Vegetables Laboratory works across commodities to improve shelf-life, overcome transportation difficulties, and produce new varieties through selective breeding and development of genomic resources (USDA, ARS, 2019c).

The investments by outside entities highlight the growing interest in curbing food loss as it pertains to all stages of the supply chain for fruits and vegetables. The strategies outlined previously often begin with the goal of reducing observable food loss. However, for food loss reduction efforts to succeed at all stages of the supply chain, there needs to be a demonstrated economic value starting with growers and following through to the final consumer (whether in a traditional market or for donated food). Regardless of impacts on food loss, some growers have begun to streamline their own supply chain to more efficiently reach the final consumer and to increase the portion of retail value they receive.

Direct-to-consumer sales channels and streamlining logistics are both gaining popularity among growers and consumers. These strategies are designed to move food more efficiently from the producer to the consumer, and/or extend the shelf-life for fresh produce. Each strategy's aim is to improve growers' share of the consumer dollar, but the effect on overall food loss is not fully known.

Access to farmers' markets or other diversified markets can be an important factor in limiting food loss in some cases. In addition to the ugly produce mentioned previously, produce that is too ripe to ship over large distances can be sold immediately to consumers in farm stores or farmers' markets, reducing the amount of produce loss. Similarly, by selling to schools that have a farm-to-school

lunch program and other local or direct markets, growers can receive benefits of diversifying their sales and selling product that might otherwise have been unsalvageable (Izumi et al., 2010). These outlets, which tend to be more locally focused and thus have a quicker turn-around for rapidly ripening product, provide an immediate outlet for produce.

While these markets operate well when established, it is typically outside the scope of a single grower to establish a farmers' market or create the infrastructure necessary to sell into a new market channel while still maintaining established market channels. Accessing new markets with new standards requires heightened management effort and expertise; however, studies have demonstrated the benefits of growers' increasing use of less traditional market channels. The increased costs of participation in local markets, such as hauling and selling produce themselves, have been demonstrated to be offset by higher prices, quicker product turnover, and reduced uncertainty in the marketplace when selling in innovative or emerging market channels (Verhaegen and Huylenbroeck, 2001). Recent research has shown that consumers buy and spend more on fruits and vegetables if they shop at a direct-to-consumer outlet, such as a farmers' market, suggesting that it may be a profitable outlet for growers with produce that may not survive cross-country shipping (Stewart and Dong, 2018). Finally, these direct outlets have been shown to open new markets for consumers who might not otherwise have had access to fresh produce, strengthening the financial incentives for growers to participate (Evans et al., 2012; Dimitri et al., 2015).

Conclusions

Many factors contribute to food loss at the farm level. This study identifies common themes and drivers, and identifies several public and private investments aimed at curbing food loss. If food is never produced with an intention of it going to landfill, this study reveals other underlying drivers of loss exist, which may include price volatility in the marketplace, labor constraints, supply chain rigidities, grades and standards, consumer preferences, or existing policies that unintentionally exacerbate food loss. Once the effects, incentives, and competing goals are considered together, one can begin to understand how to balance resources devoted to reducing food loss alongside other goals, such as maintaining farm profitability.

Reducing food loss, like any singular focus in a complex system, does not occur in a vacuum, and each action has an opportunity cost. Food loss reduction may be greatest when considered alongside other competing factors for the individual grower, processor, retailer, and consumer. If reducing food loss takes away resources devoted to farm profitability, for example, it is unlikely that any grower would choose to participate. However, if reducing food loss is considered alongside more traditional goals like improving farm income, industry adoption of food loss initiatives may be more likely. Additionally, how the issue is framed (e.g., as a distribution problem, as a way to feed hungry people, as a path to increase farm profit) may lead to different mitigation strategies that produce different “winners” and “losers.”

There are emerging retail markets and opportunities that can both alleviate food loss and improve growers' income, as evidenced by consumer interest in "ugly" or "imperfect" produce. As the conditions for food loss are multifaceted, so, too, are the strategies that alleviate that loss and improve grower welfare. This study attempts to identify likely contributing factors to food loss early in the supply chain. However, collecting and analyzing nationally representative data could identify which of the potential driving factors are most significant and highlight the opportunities to most substantially reduce food loss.

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