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Inventory Management and Food Loss on Farm: Evidence from Soybean Loss Resulting from the US-China Trade War

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Abstract

Globally, FAO estimates that about one-third of produced edible food is lost or wasted. Few knowledges were obtained regarding the causes of food loss on farm whose quantity could be substantial according to recent field measurement. This study examines and estimates the impact of inventory capacity on food loss on farm focusing on soybean production in US states from 2010 to 2018 based on the data from USDA National Agricultural Statistics Service (NASS) using a propensity score weighted difference in difference method. We find that inventory capacity exerts insignificant effects on food loss when market prices were high in 2011-2014. When the market price was unexpectedly lower than breakeven value, the unharvested rates from the states with low stock capacity increased significantly by about 2.06 percentage points. The increase in unharvesting rates from the states with higher grain stock capacity, however, was not statistically different from zero. This suggests heterogeneous ability among states with different levels of stock capacity in coping with food loss on farm. This study provides the first evidences and the first evaluations on the role of grian stock capacity on reducing the loss of soybeans on the farm. The results from this study suggests the importance of inventory management in promoting the efficiency and sustainability of U.S. food supply chain.

Keywords:

Food loss; Food waste; Difference-in-differences; U.S.-China trade war; Grain storage capacity

1. Introduction

Globally, FAO estimates that about one-third of produced edible food is lost or wasted (Gustavsson et al. 2011), which is associated with a substantial waste of resources that were used to improve nutrition and food security in the first place. In the United State, for example, this represents about 21% of water, 19% of fertilizer and 18% of cropland devoted to food that were never consumed (ReFED 2016). Currently, most food waste studies focus on the waste at consumer levels where consumers' awareness and attitudes toward food waste (Neff et al 2015; Qi and Roe 2016), and preferences to food products (Witzel et al 2018; Williamson et al 2016; Buzby and Hyman 2012; Parfitt et al 2010) are found to be the major drivers. Compared to downstream studies focused on household food waste, little is known about how and why food is lost and wasted in the early stage of the supply chain, which limits our ability to design and prioritize agriculture policies to improve the efficiency of agriculture production and reduce food loss on farm.

Food loss is commonly referred to the food removed from supply chain in the early stage, i.e., the decrease in the quantity or quality of food resulting from decisions and actions by food suppliers in the chain, excluding retailers, food service providers and consumers (FAO). Some data collection efforts based on grower interviews show the amount of food lost in the primary production could be substantial. Franke et al (2016) estimates food waste amounts in primary production in Finland, Sweden, Norway, and Denmark by conducting surveys, interviews and direct measurements. According to a Finnish questionnaire answered by 700 wheat farmers, about 16% of wheat planted for human consumption is removed from supply chain at the primary production, either left in the field or sorted out during the sorting processing. The rate of side flow varies among the four Nordic countries with an average of 23% side flow reported from Swedish 306 farmers, 5% reported from 125 Danish farmers, and 6.6% reported from 614 Norwegian

farmers. This equivalates a total of 42 million kilograms of wheat produced for human consumption never left the farm in the Nordic countries each year. If we assume only 1% of these side flow failed to end in any valuable uses (e.g., animal feed), this still accounts to approximately 4 tonnes of wheat wasted per year. In the United States, based on the data from USDA NASS, ReFED (2016) estimates that 10.1 million tons of food lost on farm annually which accounts to one sixth of the total food wasted in the U.S. every year. Though majority of this loss is tilled into soils as nutrients, few evidences show that farmers adjust the usage of fertilizer based on the food loss from previous years. Further, though rotted food can be used as nutrients for soils, leaving food produced for human consumption on farm as nutrients for soil fails to be the best utilization of the resources used during the production and therefore unharvested food on farm still represents a considerable lost economics and resources opportunities. Further, based on more recent field measurement conducted in North Carolina (Johnson et al 2018; Dunning et al 2019) and in central California (Baker et al 2019), researchers suggest that actual food loss in the field in the U.S. could be much higher than the prior interview-based estimations. For example, Baker et al (2019) found that measured edible food loss exceed growers' estimations by a median value of 157%. Therefore, given the potential high volume of loss on farm, better understandings regarding the causes of food loss in the primary production is critical.

The purpose of this study is to examine and estimate the impact of inventory capacity on food loss on farm focusing on soybean production in US states from 2010 to 2018. We rely on the county level planted yet unharvested soybean areas (USDA National Agricultural Statistics Service), or the unharvested rate hereafter, as the measurement of the degree of food loss on farm. Inventory capacity is measured at state-level including both on-farm and off-farm grain storage capacity USDA National Agricultural Statistics Service. We hypothesize that inventory stock

capacity works as a buffer that helps farmers hedge against market risks and reduce food loss on farm. Economists have long found that grain stock are used to meditate market risks and smooth consumption among rural households in developing countries (Zimmerman and Carter 2003; Carter and Lybert 2012) where households stock grains when surplus is available and sell or consume the stocked grain products when consumption is in short. However, no existing literatures discuss the impacts of the capacity of such grain stock on food loss when market price of food products are too low to justify farmers' harvesting efforts. We hypothesize that with higher capacity of stocking surplus food, when prices on the market are too low to justify harvesting efforts, farmers can motivated enough to harvest the matured food and stock them in inventory until better prices available in the future. Without enough stocking capacity, farmers in states with low grain stock capacity have to give up the matured and edible food and let them rotted in the field when market prices fail to justify their costs associated with harvesting and rescuing food on the farm.

From 2010-2018, we witnessed two years with unexpected low market prices, one in 2015 when the yield of soybean was unexpected high (USDA ERS 2016) and the other in 2018 when the price of soybean decreased dramatically due to the outbreak of trade war between China and U.S (Balistreri et al 2018; Balistreri, Zhang, and Beghin 2020). In both years we observed a spike of unharvested rates of soybean nationwide, with the states possessing fewer stock capacity suffered the most. For example, in 2018, Louisiana ran out of room to store the extra soybeans, the unharvested rate of soybean in Louisiana surged 5.6 times from 1.52% in 2017 to 10.04% in 2018. Majority of those unharvested soybean were still in good quality but rotted in the field (USDA NASS, AJOT/CNBC 2019 January). However, the increase of unharvested rates among the states with better inventory capacity was much smaller. For example, Iowa owns the highest

grain stock capacity in our sample (e.g., 3.6 billion bushels in 2018). The unharvested rate of soybean in Iowa only increased 0.6 percent points from 0.60% to 1.21% in 2018. This suggests highly heterogeneous abilities of mitigating food loss in the field among the states with different inventory capacity.

To empirically test the role of inventory capacity on smoothing market risks and mitigating food loss on farm, we use a difference in difference model augmented with propensity score weighting by comparing the unharvested rates between the states with low and high inventory capacity when market prices unexpectedly dropped below the breakeven value. In particular, we define the states with grain stock capacity higher than national median as the treated group and the other soybean growing states as the control group. We exploit the distinct abilities that these two types of states have in responding to significant drop in soybean prices in term of food loss on farm. We break our estimation period into pre, high price period mainly in 2010-2014 when market prices each county received were higher than soybean breakeven value $8.98, and post, low price period mainly in 2015-2018 when market prices that some or all counties received were lower than $8.98. The sudden declines in soybean prices are driven by global expansion of soybean acres and exacerbated by Chinese retaliatory tariffs in the ongoing US-China trade war in 2018, both of which are exogeneous to farmers' decisions. To control for the potential confounding bias induced by sample selection, we weighted all groups to be similar to the states with high stock capacity in a good year of market (Staurt et al 2014). We found that, as long as weather conditions at county levels are controlled, during the years when market prices are high and can rationalize farmers' harvesting efforts, the unharvested rates between the states with high versus low stock capacity weren't significantly different from each other. In fact, the yearly patterns between the two groups were similar and parallel in 2010-2014 when the market prices were always higher than the

breakeven value. When market price unexpectedly plunged in 2015 due the unexpected high yield of soybean and in 2018 due the trade-war between China and U.S., the unharvested rates among the states with low stock capacity increased about 3 percent. Compared to the low capacity states, states with higher stock capacity suffered about 3 percentage points less on unharvested production, which suggested a nearly perfect risk smoothing in term of minimizing food loss on farm.

This study provides the first evidence and the first evaluation on the efficacy of inventory management on reducing the loss of soybeans on the farm. Using a panel data of county-level soybean production, our study provides the first causal estimate of the efficacy of inventory management and grain storage capacity in reducing the loss of soybeans on the farm. The results from this study reveals an important cause of food loss in the primary production stage and highlights an understudied channel to reduce food loss on farm as opposed to merely focusing on reducing food waste produced by the consumers. Our results also show the mediating or buffer effect of the inventory management is most salient facing significant price shocks such as U.S.-China trade war, and it impacts low-storage-capacity states most severely.

The remainder of the article is organized as follows. The next section describes the measurement of soybean loss in the field in the U.S. The following sections discuss the data and the identification strategy. The next section presents main results and robustness tests. The final section provides conclusions, discussion and recommendations for future research.

2. Soybean loss in the field

The scale of soybean production in the U.S. varies dramatically by states. About more than 80 percent of soybeans are cultivated in the Midwest especially upper Midwest, with Illinois, Iowa

and Minnesota as the leading soybean production states (Figure 1). In 2018, more than 10 million acres of soybeans were planted in Illinois while approximately only 1.2 million acres planted in Louisiana. The scale of the agricultural production affects the development of related facilities and infrastructures, e.g., grain stock capacity, which could significantly impact famers' planting, harvesting and selling strategies and in the meantime affect the generation of food loss in the field.

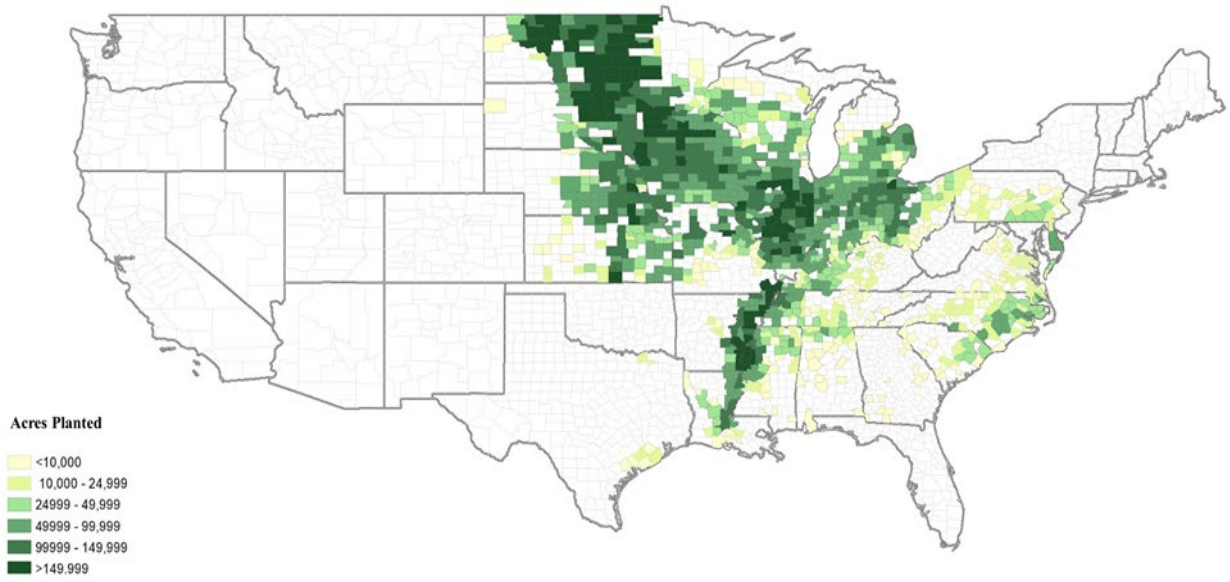

Fig 1 Planted Acres by U.S. County in 2018 (Data source: USDA NASS)

Food loss in the field attracts more attention in the recent years as researchers found larger than expected amount of edible food was never able to leave the farm (Baker et al 2019). In 2018, according to USDA NASS, about 1.2 million acres of planted soybean were never harvested, which represents approximately 62 million bushels of soybeans unharvested and wasted in a single year. Illinois leaded all states and had more than 282 thousand acres of soybean unharvested. Louisiana, on the other side, with only about one tenth of acres of soybean planted as Illinois lost as much as 45% of the acres of soybeans that Illinois lost (126,000 acres). This suggests that a

highly heterogenous severity of the field loss among the states. According to USDA NASS, the unharvest rate of soybean in the U.S. in 2010-2018 varied significantly by states, ranging from less than 1% in Indiana to 23% in Texas and 15% in Louisiana (Figure 2). Therefore, it's essential to understanding the factors that affect farmers' harvesting and wasting decisions so that agricultural policies and initiatives can be prioritized to improve the food loss in the field.

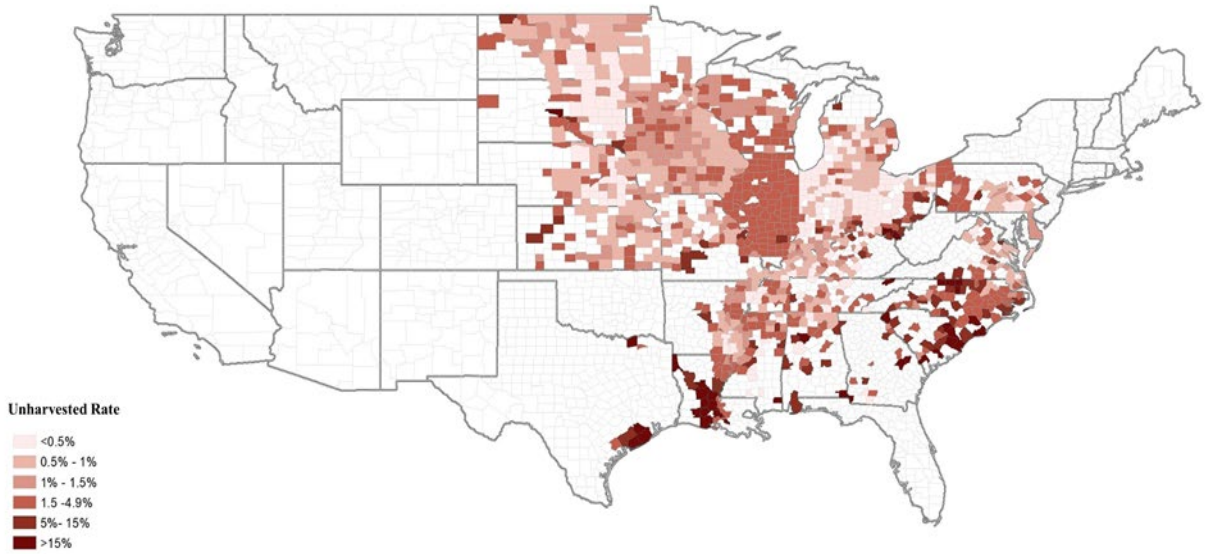

Fig 2 Percentage of acres of planted soybean unharvested by States in 2018 ((Data source: USDA NASS))

Soybean in the U.S. is planted in May-June and is harvested in October (Figure 3). A rational farmer makes his harvesting decides based on the marginal cost and marginal benefit of harvesting given the observed market conditions. In that case, farmers rarely consider the sunk costs of production but instead they compare the available sale opportunities on the market to the labor costs of harvesting the soybeans. For example, in 2018, due to the trade war between United

States and China, the soybean price in October plunged dramatically below $8 which was much lower than the average breakeven price (e.g., $8.98) that can justify the harvesting efforts. As a result, the market price in 2018 was so low that a substantial increase of unharvests and food loss was observed in the field.

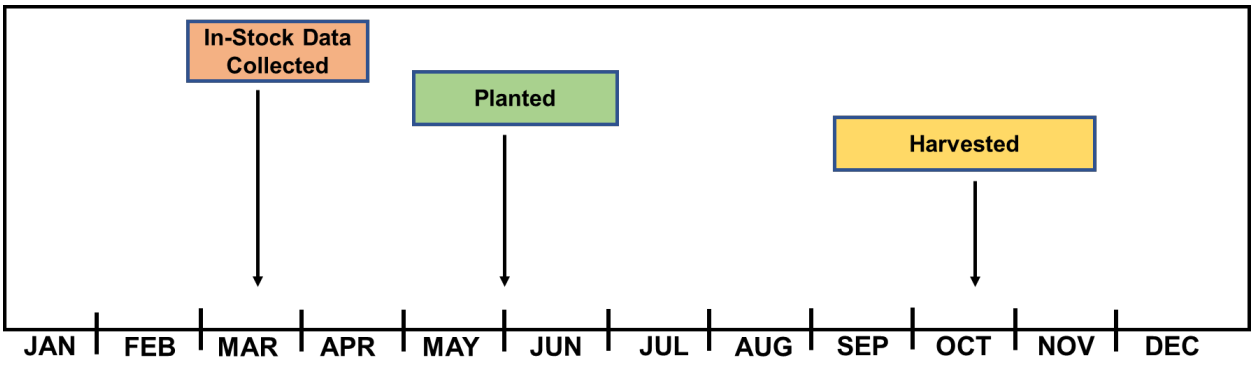

Fig 3 Timeline of soybean growing season (USDA)

If a farmer has access to good enough inventory facilities that can stock surplus soybean in a bad year until the market price increases and the price can provide positive profits, in that case, the marginal benefits of harvesting the surplus food can justify its marginal cost even in a bad year when the market price is unexpectedly low. By this way, inventory capacity works as a buffer that mitigates the risks from the market and reduces food loss by incentivizing harvesting efforts even when market conditions are not favorable. For states with low stock capacity, however, without such buffer, we hypothesize that the amount of food loss from those states fluctuates substantially by the price on the market, i.e., with low food loss when market price is high and high food loss when price goes low.

3. Data and empirical approach

To understand the impact of inventory capacity on soybean loss n farm in the U.S., we use soybean production data from National Agricultural Statistics Service (NASS) from USDA in 2010-2018. Food loss is measured by acres of soybean harvested adjusted by weather conditions, i.e., the differences between acres of soybean planted in May-June and acres of soybean harvested in October adjusted by weather conditions. We assume that the quality of soybean on the harvested and unharvested land are fairly similar when weather conditions are well controlled (i.e., when the damage induced by extreme weather is controlled). Field measurement of unharvested crops is commonly used to estimate loss in the existing literature (i.e., ReFED (2016) and WRAP (2017)) when better in-field measurements are not available. Though some concerns arise when a same field can be harvested for multiple times, it's unlikely that a same soybean field will be harvested for multiple times due to the mechanized nature of the soybean harvesting in the U.S and time constraint during the harvest season when the time window for field work is short. Therefore, we are fairly confident that the rate of planted acres unharvested works as a reasonable measurement to evaluate soybean loss on farm.

Figure 4 presents the total acres of soybean unharvested in the U.S. from 2010 to 2018. Damage caused by unfavorable variation of weather conditions can be one of the leading factors that contribute crop unharvest. For example, the severe drought in 2011-2012 ends in on average about 750 thousand acres of soybean unharvested in the U.S. every year. In many cases, however, when extreme weather happens, the damaged food caused by unfavorable weather conditions is less suitable for human consumption. According to the definition from USDA ERS and United Nation FAO, only the edible food removed from the supply chain should be considered as food waste. Therefore, in all the following regression models, we include weather conditions at county

level to control for the soybean unharvest caused by severe weather. Nevertheless, in some years when weather conditions were relatively desirable for soybean planting, growing and harvesting, like 2015 and 2018, we still observe large spikes on the acres of soybean unharvested. This suggests that factors other than weather conditions can also affect the generation of food loss on farm in a remarkable way.

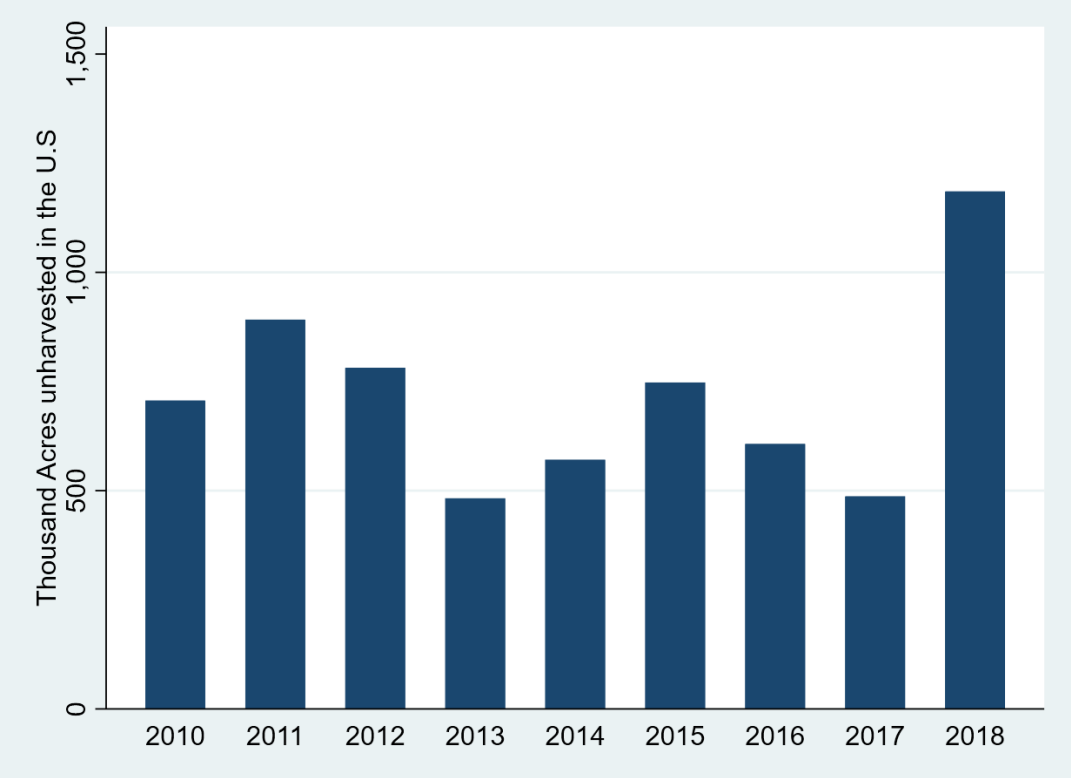

Fig 4. Acres of soybeans unharvested in the U.S. in 2010-2018

In this study, we are interested in whether unexpected changes in market conditions explain some soybean loss on farm in the U.S. For example, we witness a spike of soybean unharvested in 2015 when weather conditions were relatively favorable and the yield of soybeans was unexpectedly high. We also observed another spike of soybean unharvest in 2018 when the market price of soybean plunged as China imposed a 25% tariff on soybeans imported from America in April 2018 (wikipedia). Those observations are consistent with our hypothesis that, when market

price is lower than the breakeven value, farmers without access to necessary inventory capacity have to give up harvesting and leave edible soybean in the field unharvested and wasted.

To evaluate this hypothesis, we split our study periods into "good years" versus "bad years". According to Stark and Watkins (2019), the breakeven value for soybean is about $8.98. If the market price of soybean that county *i* received was higher than $8.98 in year *t*, we define that county *i* had a "good year", otherwise it suffered a "bad year". In this case, variable $Good\ Year_{it}$ varies by time and by location. From 2010 to 2014, due the undesirable weather conditions around the U.S., the supply of soybean remained a relatively low level. As a result, the price of soybeans stayed relatively high during the entire five years and, from 2010-2014, none of the counties in our sample experienced a bad market year by our definition (see red line in Figure 5). Since 2015, the market prices of soybean decreased and stayed low due increase of supply and the rise of inventory stock. Starting from 2015, a positive number of counties started to receive prices lower than breakeven value and suffer "bad years", i.e., nearly 60% of the counties suffering a "bad year" in 2015. In March 2018, the trade war between U.S and China outbroke when Trump asked the United States trade representative (USTR) to investigate applying tariffs on US$50–60 billion worth of Chinese goods. Responding to that, Ministry of Commerce of China announced an increase of tariffs on 128 products imported from the U.S, including a 25% tariff on soybeans. Following the increase of tariff, the prices of soybean decreased dramatically. For example, Central Illinois soybean prices plummeted from $9.86 per bushel on June 1st 2018 to just above $8.00 in early July (USDA ERS 2018), which was much lower than the breakeven value that requires to justify U.S farmers' harvesting efforts. Since the increase of tariff was announced after soybean planting season (March), the plunge of market price was unexpected to farmers and few

adjustments farmers can make to respond to this sudden market changes. As a result, 98% of counties in our sample experienced a “bad year” in 2018.

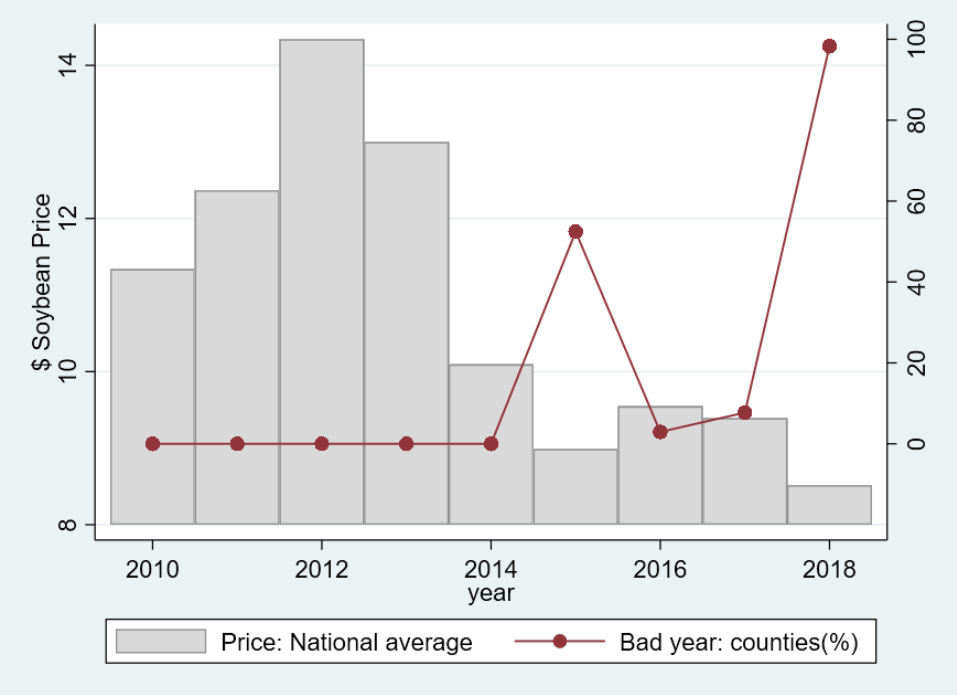

Fig 5. % of counties received a soybean price lower than $8.98

Inventory capacity is measured by the grain stock capacity available at state level in the end of each year (USDA NASS). The bushels of soybean stocked both on-farm and off-farm were measured in March as a measurement of soybean stocked in the beginning of each growing season. Market prices of soybean were collected in December when the harvesting almost ends as a summary of the market price for that year. Temperature and humidity conditions were collected at county level to control for the damage induced by extreme weather conditions.

Table 1 presents the summary statistics for the soybean production in the U.S. from 2010 to 2018. On average, 578 acres of planted soybean left unharvested per state annually which accounts to approximately 2% of the 60 thousand planted acres.

Table 1. Summary statistics

Variable	Obs	Mean	Std.Dev.	Min	Max
Acres of soybean unharvested	11174	578	1114.06	0	31000
Acres of soybean unharvested (%)	11174	1.93	4.19	0	71.43
Soybean in stock: 10^9 bushels in Mar	11174	.08	.09	0	.37
Soybean planted (10^6 Acres)	11174	.06	.06	0	.53
High Capacity: counties (%)	11174	.62	.48	0	1
Grain Stock Capacity: 10^9 bushels	11174	1.19	1.06	0.02	3.60
Bad year: counties (%)	11174	.17	.37	0	1
hdd	11074	6.07	15	0	297.13
vpd_dew	11074	8.05	1.79	4.1	20.13
s_ppt1000	11174	1.01	.32	.21	2.3

To determine the groups with high versus low stock capacity, we ranked soybean growing states by the grain stock capacity that it obtained each year. The ranking among those states remains roughly same over the entire study period, though some states had data missing in certain years. Therefore, we split the sample into high and low stock capacity groups by their average grain stock capacity over 2010-2018 (Table 2). The states obtaining higher grain stock capacity than the national median are defined as high stock capacity states, while the rest half are categorized as low stock capacity states. Table 2 presents the average stock capacity for each state and the categorization of high versus low stock capacity groups. The first 14 states, from Iowa to Arkansas, are identified as high stock capacity states and the other 14 states, from Oklahoma to South Carolina, were found to obtain fewer stock capacity. Iowa sees as the state with the highest grain stock capacity among all 28 soybean growing states in the U.S, with 3.44 trillion bushels

stock capacity per year, while South Carolina owns the lowest stock capacity with only 18 billion bushels available per year.

Table 2. Grain stock capacity at state level

State Name	High Capacity (10^6 bushels)	Low Capacity (10^6 bushels)
Iowa	3440	
Illinois	2920	
Minnesota	2210	
Nebraska	2040	
Kansas	1400	
Indiana	1330	
North Dakota	1280	
South Dakota	1040	
Ohio	950	
Texas	797	
Missouri	767	
Wisconsin	708	
Michigan	503	
Arkansas	496	
Oklahoma		313
Kentucky		279
Pennsylvania		196
North Carolina		194
Mississippi		183
Tennessee		150
New York		147
Louisiana		120
Georgia		113
Virginia		89.1
Alabama		70.4
Maryland		52.5
Delaware		22.8
South Carolina		18.3

3.2 Empirical strategy

3.2.1 Difference – in – difference analysis

We followed a difference – in – difference (DID) approach to identify the effects of inventory capacity on reducing food loss in the field by mitigating market risks. We compared the difference in the acres of unharvested between high and low stock capacity states in good versus bad years following Eq (1):

$$Unharvested_{it} = \alpha_0+\beta_1 High_i+\beta_2 Bad_{it}+\beta_3 High_i \, x \, Bad_{it} +\mathbf{\theta X}_{it}+Year_t+Region_i+\epsilon_{it} \quad (1)$$

where β_1 captures the initial differences between the high ($High_i$ =1) and low stock capacity states ($High_i$=0) in a normal year. When market prices that farmers in county I facing were lower than the breakeven value, we define Bad_{it}=1 and β_2 estimates the increase of unharvest in a bad year. The coefficient β_3 is the coefficient of interest which compares the differences of unharvest increase between states with high stock capacity and the states with low stock capacity when the market price unexpectedly dropped below the breakeven value (i.e., ϵ_{it} isn't correlated with Bad_{it}). A significant positive β_3 suggests an advantage that high capacity states obtain over the state with lower stock capacity in hedging against uncertainty from the markets and mitigating food loss under bad market conditions. In our analysis, we controlled for the variations of weather to exclude the unharvest induced by severe weather. Acres of soybean planted and the bushels of soybean stocked in March at county level were also included to control for the impacts of production scale on food loss in the field. Year fixed effects ($Year_t$) are included to control for the yearly variations that are applied to all counties in the country and region fixed effects ($Region_i$) are included to capture time-invariant unobserved factors within each region.

The validity of the DID specification depends on the parallel trend assumption, i.e., the low stock capacity states can work as a valid control for the high capacity states, in the sense that, in a normal year when the market price is higher than the breakeven value, soybean harvesting from the two groups should be similar and follow a parallel trend. In our case, the severe weather

conditions in early 2010s contributed to the high market prices in 2010-2014 when no counties in our sample experienced a market price that was lower than their breakeven value. During these years, the unharvest rates between the low and high stock capacity states are very similar (p=0.422 Table 3) and the yearly trends are relatively parallel (Fig 6), which provides empirical evidences supporting the parallel assumption of DID specification.

3.2.2 Propensity Score Weighted Difference in Difference

DID method provide unbiased estimations of treatment effect if the trend between the treatment and control groups would have been the same in absence of interventions, i.e., higher and low stock capacity states should have similar food loss patterns over time when the market price is higher than the breakeven value. Some concerns that states with higher stock capacity e.g., Iowa and Illinois, may obtain other facility and infrastructure that can provide better supports to their farmers during bad market years and hence alleviate the food loss on the farm. In that case, the estimation of β_3 from DID is biased. To address this concern, a propensity score weighted difference in difference method was applied to balance characteristics of the low and high stock capacity states (Stuart et al 2014, Zeng et al 2010)

In our case, the propensity score, commonly defined as the probability of being assigned to treatment group, can be used to balance the conditional distribution of covariates for the treatment and the control group. Based on a series of simulations, Stuart et al (2014) shows that, with selection bias, the performance of the naïve DID models degrades and propensity score weighting strategies can largely improve DID's performance. Stuart et al (2014) constructs propensity score in four approaches and find that the four-group weighting approach provided the most accurate estimations, i.e., yields unbiased effect estimations with better coverage rates. Therefore, in this study, we use DID model in conjunction with the four-group propensity score

weighting approach to estimate the robust effects of inventory capacity on reducing food loss in bad market years.

Following Stuart et al (2014), we estimate, in each time period, the probability each state of being one of the 2 (high versus low stock capacity states) x 2 (good versus bad market year) groups $e_k(X_i)$: the probability of being group k, for k=1-4 where group 1 represents states with high stock capacity in a good year. The weights are calculated in such a way that each of the four groups is weighted to be similar to group 1, the treatment group in the baseline period:

$$W_i = e_1(X_i)/e_g(X_i) \quad (2)$$

where *g* refers to the group that the state *i* was actually in. Therefore, the states with the high stock capacity in a good year will receive a weight of 1, while states in other groups will receive a weight that is proportional to their probability of being group 1. Logistics models are used to predict the probability of being each of the four groups.

4. Results

Figure 6 plots percentage of planted soybean unharvested in the states with high (red line) versus low (green line) grain stock capacity adjusted by weather conditions, scale of the production and year and state fixed effects in 2010-2018. We compare the yearly unharvested patterns to the changes of soybean prices on market (shadow areas). The dotted line represents the assumed breakeven value to justify farmers' harvesting efforts. When the market prices were high in 2010-2014, the adjusted percentage acres unharvested at county level were low both in the high and low grain stock capacity states and the yearly patterns between the two were relatively parallel. When the market price dropped below the breakeven value in 2015, the adjusted unharvested rates

increased dramatically among the states with low grain stock capacity. As the market price rebounded in 2016-2017, states with low stock capacity enjoyed a decrease of soybean unharvest and hit its lowest unharvest rate in 2017. The states with high stock capacity, on the other hand, maintain a relatively low and flat unharvested rates over all years from 2010-2017. In 2018, due to a sudden and substantial decrease in soybean price caused by the trade-war between China and United States, the percentage acres of soybean unharvested surged both in low and high stock capacity states, though the increase of unharvest and food loss from the high stock capacity states was much smaller than the ones from the low stock capacity states. The surge of unharvest among the high stock capacity states may suggest high stress in grain stock capacity even among the high stock capacity states and hence their unharvest patterns were approaching to the ones from the low stock capacity group.

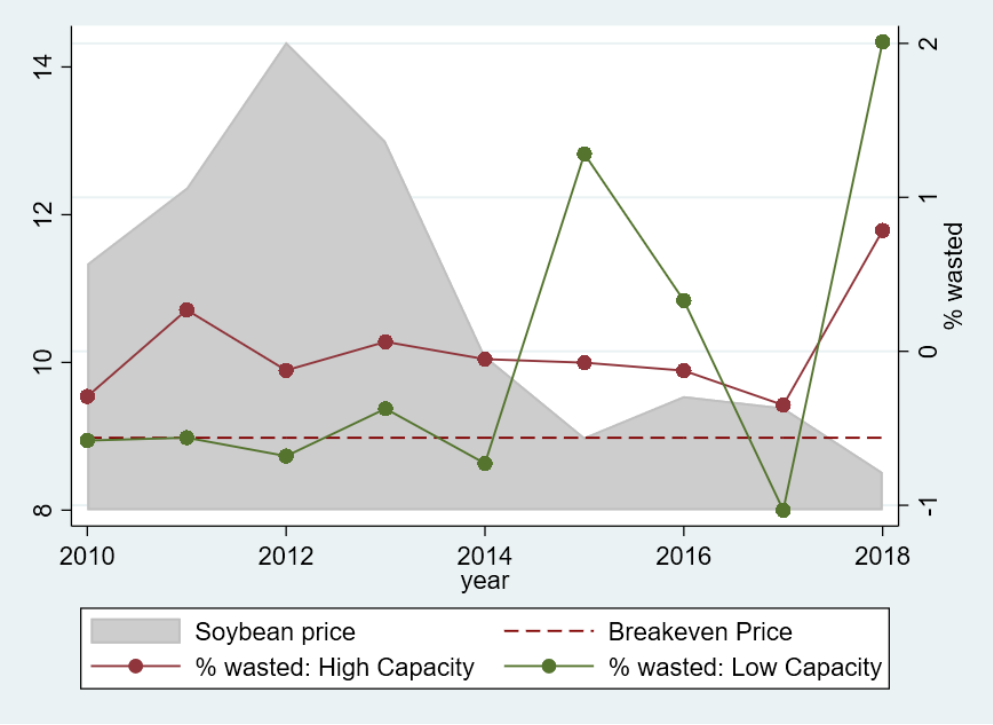

Fig 6 The relation between unharvested rates and market prices of soybean

Table 4 presents the estimated effects of inventory capacity on hedging against market risks and mitigating food loss in an unweighted difference-in-difference models. We estimated such effects both at extensive margin in column (1) and (3) and at intensive margin in column (2) and column (4). For all specifications, year fixed effects are included to capture time variant but county invariant unobservable. Agricultural district fixed effects are included in column (1)-(2) and state fixed effects are included column (3)-(4) to control for time invariant factors at regional level.

According to column (1)-(2), given all others constant, in a good market year when market price is higher than breakeven value, the unharvested rates from states with high stock capacity is about 0.86 percent points lower than the ones from the other states. In a bad year of market, on average, a state sees an increase in soybean unharvested for about 2 percent points. Compared to the states with low stock capacity, states with high stock capacity suffered about 1.9 percent points less increase in unharvested rate, which represents 313 fewer acres or 16,307 fewer bushels of soybeans (if we assume the yield of soybean is 52.1 bushel per acre) wasted on farm per state per year. When state fixed effects are included in column (3)-(4), the results remain robust and roughly the same, though the magnitude of the treatment effects are larger (-2.13 versus -1.85 and -520 versus -313).

Even though differences between the treatment and control groups (high versus low stock capacity states) at the baseline (in a "good" year) doesn't threat the validity of the DID estimations, some may concern that the unobserved factors that drive the differences between the treatment and control groups in the baseline period may be correlate with the distinct abilities between the two groups in responding to the changes over time. If that is the case, such unobserved factors could bias the estimations. Therefore, in this study, a propensity score weighting method is applied to correct for such confounding bias by balancing the states with high and low stock capacity on their

observed characteristics. Column (5)-(8) reports the estimations when each observation is weighted by a predicted weight W_i (Eq (2)). When all groups are weighted to be similar to the high stock capacity states in a good year of market based on observables, e.g., the scale of the soybean production and the climate conditions at county level which may be associated with both the food loss on farm and the availability of inventory capacity within the states, the estimated treatment effects increased by 50-180%. For example, during a year with market prices lower than breakeven value, a state with higher stock capacity suffered 3.34 percent points (compared to 2.13 percent points from the unweighted regression) less soybean loss than the other states, which is equivalent to 976 (compared to 519) more acres of soybean harvested and saved. . The increase of unharvest in a bad market year from a state with low stock capacity is about 1026 acres (compared to 402 acres), which equivalates to about 3.26 (compared to 1.84 percent points) percent points increase in unharvest. The increase of unharvest from a state with higher grain stock capacity, however, is about 980 acres (or 3.34 percent points) fewer.

Table 4. Regression Results

	Unweighted Difference in Difference				Weighted Difference in Difference			
VARIABLES	(1) Acres Unharvested	(2) Unharvested (%)	(3) Acres Unharvested	(4) Unharvested (%)	(5) Acres Unharvested	(6) Unharvested (%)	(7) Acres Unharvested	(8) Unharvested (%)
High grain capacity	-87.164**	-0.856***			-155.579	-1.694***		
	(39.441)	(0.143)			(121.779)	(0.446)		
Bad market year: Price < $8.98	307.629***	2.057***	401.584***	1.837***	882.119***	4.128***	1,026.277***	3.262***
	(63.947)	(0.231)	(66.047)	(0.245)	(167.912)	(1.004)	(187.872)	(1.026)
High capacity x bad year	-312.610***	-1.853***	-519.651***	-2.132***	-844.556***	-3.945***	-979.628***	-3.335***
	(55.593)	(0.201)	(58.524)	(0.217)	(136.751)	(0.613)	(142.654)	(0.525)
p value: Bad + High x Bad	0.923	0.275	0.027**	0.135	0.702	0.758	0.695	0.923
Observations	11,073	11,073	11,074	11,074	11,073	11,073	11,074	11,074
R-squared	0.217	0.274	0.231	0.252	0.221	0.418	0.232	0.413
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ag District FE	Yes	Yes	No	No	Yes	Yes	No	No
State FE	No	No	Yes	Yes	No	No	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

5. Discussion and Conclusion

In this study we exploit and estimate the impacts of inventory capacity on food loss using soybean production in U.S as an example. We find that, when food loss is adjusted by climate conditions (e.g., excluding the loss induced by severe weather conditions) and the scale of production, food loss on farm between states with high versus low grain stock capacity are relatively similar (i.e., not significantly different from zero) when market prices are higher than breakeven value and can justify famers' harvesting efforts. When market prices unexpectedly plunged under the breakeven value, however, the amount of food loss from states with fewer grain stock capacity surges while the states with higher grain stock capacity manage to maintain a relatively low level of food loss, and the differences between the two states become statistically significant. Compared to the substantial increase in unharvest among the low inventory capacity states, states with high stock capacity demonstrate a remarkable ability in smoothing market risks that leads to an almost insignificant increase in food loss on farm, either in the acres of unharvested (p=0.695) or percentage of planted soybean unharvested (p=0.923), under unfavorable market conditions.

This is the first study exploiting the role of inventory management on food loss on farm. The results from this study suggests the vulnerability of states with low stock capacity when faced with an unstable and fluctuating market with high uncertainty. Food loss represents a substantial waste of money, energy, and nutrients. Better inventory capacity and facilities would improve states ability to better cope with uncertainty and risks from the market and improve the efficiency, profitability and sustainability of the food supply chain by reducing the loss of mature and edible food on farm. We note that some states, e.g., Louisiana, may be equipped with climates that are unfavorable for grain product stocking. Therefore, the cost of grain stocking should be heterogenous among the

states and more careful and locally determinative cost-benefit analysis is required to understand the feasibility of inventory development in various areas.

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