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Impacts of the COVID-19 pandemic on the dairy industry: Lessons from China and the United States and policy implications



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Abstract

The purposes of this study are to assess the COVID-19 pandemic's impacts on the dairy industries in China and the United States and to derive policy recommendations for enhancing the dairy industries' resilience to pandemics and other market shocks. Specifically, data from the two nations are used to analyze and compare the mechanisms through which the pandemic has affected their dairy industries and to discuss potential lessons from their experiences. The findings suggest that this pandemic has heavily affected the dairy industries in both China and the United States through similar mechanisms, such as decreased farmgate milk prices, disruption and difficulties of moving milk within the supply chains, worker shortages, increased production costs, and lack of operating capital. There were also significant differences in the affecting mechanisms between the two nations, including transportation difficulties from widespread road closures and significant reduction in holiday sales of dairy products in China, and the shutdown of many dairy processors in the United States due to the closing of schools, restaurants, and hotels. While government financial reliefs are highly needed to help many dairy farms and processors survive this pandemic in the short term, the dairy industries and governments need to work together to develop long-term strategies and policies to balance the industries' efficiency and flexibility, product specialization and diversification, supply chain integration and local food systems, and market mechanisms and policy regulations and interventions.

Keywords: impacts of the COVID-19 pandemic, dairy industry, China, the United States

1. Introduction

The COVID-19 pandemic has heavily impacted many agricultural sectors around the world (Barichello 2020; Brewin 2020; Kerr 2020; Morton 2020; Pulighe and Lupia 2020; Siche 2020; Stephens *et al.* 2020; Timilsina *et al.* 2020; Zhang *et al.* 2020). Among the sectors that have suffered the most is the dairy industry because dairy products are highly perishable and depend on integrated and time-sensitive supply chains (BBC News 2020; Drury 2020; Jin 2020; Li

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2020; Marshall 2020; Skerritt and Hirtzer 2020; Weersink *et al.* 2020; Yaffe-Bellany and Corkery 2020). For example, it was widely reported in China in February and March 2020 that many dairy farms, especially small ones, could not sell their milk even at lower prices, and some had to dump milk (Hua *et al.* 2020; Jin 2020). In the United States, it was estimated that about 5% of the country's milk output in April 2020 was dumped, and the percentage was estimated to be higher in May and June 2020 (Yaffe-Bellany and Corkery 2020). Also, as a response to the meat shortage and milk surplus in the pandemic, U.S. dairy farmers sent 2.3% more milking cows to slaughter in April 2020, and the total number of milking cows in the United States could drop by up to 90000 in 2020 (Skerritt and Hirtzer 2020). Similarly, many dairy farms in Canada and the United Kingdom were also reported to be struggling to stay in business and many of them had to dump milk due to sharply decreased demand for milk and other dairy products during the pandemic (BBC News 2020; Drury 2020).

While the COVID-19 pandemic's impacts on the dairy industry have been widely reported around the world, there is a great need for economic and policy studies, especially comparative analyses, in order to understand the mechanisms through which the pandemic has directly or indirectly affected the dairy industry. Such studies and analyses can also help to derive policy recommendations and industrial strategies for reducing the impacts of this and future pandemics and to enhance the industry's resilience to market shocks. This study contributes to the literature by assessing the COVID-19 pandemic's impacts on the dairy industries in China and the United States through a comparative analysis, discussing potential lessons from the two large dairy nations with significantly different characteristics in their dairy industries, and deriving recommendations for developing policies and industrial strategies that could enhance the resilience and

sustainability of the dairy industry.

As shown in Table 1, the dairy industries in China and the United States have significantly different characteristics. First, as compared with the United States, China has a larger number of dairy farms but significantly smaller herds and lower milk yields. China's dairy industry, as a relatively young farm sector, expanded rapidly in the 1990s and 2000s but the growth was largely dominated by small farms with low productivity. For example, China had nearly 2.6 million dairy farms in 2008, but about 2 million of them had fewer than five cows (PwC Network 2019). Although the number of dairy farms dropped to 661760 in 2018, largely due to stricter environmental regulations and increased market competition in favor of large farms, China's national average herd size and milk yield in 2018 were only 16 cows per farm and 3.00 metric tons of milk per cow per year, respectively, as compared to 273 cows per farm and 10.61 metric tons of milk per cow per year in the United States in 2019. On the other hand, China's commercial dairy farms have significantly larger herds and higher milk yields than the national averages. For example, for dairy farms with more than 500 cows in 2018, their average milk yield was 7.53 metric tons per cow per year (PwC Network 2019).

Second, the U.S. population was less than 25% of the Chinese population in 2019, but the country's milk output (99.02 mmt) was more than three times that of China's milk output (32.01 mmt), resulting in an annual per capita milk and cheese consumption rate of 64.00 and 18.14 kg, respectively, in the United States, but only 12.00 and 0.10 kg in China. Third, ultra-high temperature (UHT) milk has a market share of more than one-third in China but less than 3% in the United States. The implications of this difference will be discussed in a later section. Fourth, while the United States has been a large exporter of dairy products for decades, China has emerged as a large importer of many dairy products such as milk powder and whey from the

Table 1 Basic information about the dairy industries in China and the United States in 2019

	China	The United States
Total milk output (mmt)	32.01	99.02
Rank in the world based on total milk output	3rd largest	The largest
Average per cow milk production (t yr ⁻¹)	3.00 ¹⁾	10.61
Number of dairy farms	661760 ¹⁾	34 187
Average herd size (milk cows)	16.00 ¹⁾	273
Average farmgate milk price (USD kg ⁻¹)	0.56	0.40
Average per capita milk consumption (kg yr ⁻¹)	12.00	64.00
Average per capita cheese consumption (kg yr ⁻¹)	0.10	18.14
Market share of UHT milk (%)	More than 35%	Less than 3%
International trade of dairy products	Largest importer	4th largest exporter
Share of dairy imports in total consumption	About 35%	Less than 2%
Share of dairy exports in total production	Less than 1%	About 15%

¹⁾ For all dairy farms in China in 2018 (PwC Network 2019).

Data source: Data in this table are mainly from USDA (2020), Office of Dairy Management (2015–2019), and PwC Network (2019).

United States and other major dairy exporters in the past two decades (Wang *et al.* 2010; Wang and Zou 2020).

The dairy industries in China and the United States are significantly different in many aspects but both have been heavily affected by the COVID-19 pandemic. In China, the pandemic started in Hubei Province in January 2020, spread quickly to many other regions in China, and was largely under control by the end of April 2020. In the United States, COVID-19 was detected in early March and caused more death and other damage than in China and all other nations. China and the United States may provide an excellent case for assessing how the pandemic has affected the dairy industry and what lessons we could learn from this pandemic.

The major objectives of this study are to assess the COVID-19 pandemic's impacts on the dairy industries in China and the United States, to analyze and compare the mechanisms through which the pandemic has affected the dairy industries in the two nations, to discuss the potential lessons from the two large dairy nations, and to derive recommendations for developing more resilient policies and industrial strategies. Specifically, this paper will address the following research questions: How has the COVID-19 pandemic affected the dairy industries in China and the United States? What are the similarities and differences in the impacts and mechanisms behind the impacts between the two nations? What lessons can we learn from the two large dairy nations? What policy interventions and industrial strategies may help to enhance the resilience and sustainability of the dairy industries in the two nations and around the world?

This paper is organized into five sections: Following this introduction section, Section 2 introduces the data and methods, Section 3 analyzes and compares the pandemic's impacts on the dairy industries in China and the United States, Section 4 discusses the potential lessons from the two nations and the corresponding policy implications, and Section 5 summarizes the concluding remarks and discusses the data limitations of this study.

2. Data and methods

Data used in this study are from two major sources: (1) secondary data from media reports, dairy cooperatives, farm organizations, extension services, etc. in the United States and China, and (2) primary data from an online survey of 128 dairy farms in China conducted by the Rural Development Institute of the Chinese Academy of Social Sciences from February 20 to March 5, 2020. It was likely the first survey for assessing the COVID-19 pandemic's impacts on dairy farms in China and no similar surveys have yet been reported in the United States or other major dairy nations. Although

many researchers, extension professionals, farm educators, loan officers, and policymakers in the United States are very interested in collecting primary data from dairy farmers and processors to assess the pandemic's impacts on their businesses and the actions they have taken to deal with the pandemic, it is agreed that it is inappropriate to ask dairy farmers and processors to complete a survey when they are struggling with their operations in the midst of the pandemic.

Data from the above sources are compiled and analyzed to address the research questions introduced in the previous section. Because the impacts of the COVID-19 pandemic have been observed only since January 2020 in China and since early March in the United States, the limited data are not feasible for more quantitative analyses. The analysis of the pandemic's impacts in China is based on both primary data from an online survey of dairy farms and secondary data from other sources. The analysis of the impacts in the United States, however, is based solely on secondary data, as there were no primary data available for analysis. On the other hand, this paper is likely one of the first studies of the COVID-19 pandemic's impacts in two large dairy nations.

3. Results

This section first reports our assessment of the COVID-19 pandemic's impacts on the dairy industries in China and the United States and then discusses the similarities and differences in how the pandemic has affected dairy industries in the two nations.

3.1. Impacts of the COVID-19 pandemic on the dairy industry in China

This subsection first assesses the pandemic's impact on China's dairy industry using secondary data and then analyzes the impacts using primary data from a nationwide survey of 128 dairy farms conducted from February 20 to March 5, 2020.

According to secondary data from China, the major impacts of the COVID-19 pandemic on China's dairy industry were in three main areas: First, the pandemic significantly reduced labor and feed supply for many dairy farms and increased the production costs. On January 23, 2020, the Chinese central government imposed a lockdown in Wuhan City, a large city with 11 million people. Shortly thereafter, almost all the 1.4 billion people in China, except medical professionals and some essential workers, were ordered to stay home. Many local governments and communities also took extreme actions to stop the spread of the coronavirus, such as closing roads and restricting access to highways. As a result, many employees could not return to work on the dairy farms after the Chinese New Year holiday. Nationwide

quarantines, disrupted transportation, and concerns about safety resulted in a shortage of farm labor, and difficulty sourcing feed and other farm inputs. These shortages significantly increased the production costs for many dairy farms. According to data from Economic Daily (2020), about 60–70% of the commercial dairy farms reported a shortage of workers in February 2020 and an increase of about 5–10% in average feed costs. All the precautions taken to protect workers and cows from the coronavirus also increased the operating costs of dairy farms.

According to data from the State Council of China (2020), by February 17, 2020, only 6 384 or 66% of the 9 711 feed processing companies in China were reported to be operating, as compared to 90% on the same date in previous years. In terms of the prices for major feed inputs, corn prices increased 1.8% and soymeal prices increased 1.1% in February 2020 as compared to that in the previous month.

Second, the sharp decrease in demand for milk and other dairy products resulted in significant surpluses and decreased farmgate prices. The shutdown in Wuhan and many other cities, along with the nationwide quarantines, significantly reduced the demand for milk and other dairy products. The Chinese New Year holiday is usually a period with strong demand for high-quality dairy products that have a long shelf life and do not require refrigeration. Such products are widely available in China due to the use of UHT processing. In 2020, this special demand was entirely absent due to the nationwide quarantines. While schools, colleges, and hotels in China purchase lower amounts of milk and other dairy products than similar entities in the United States, Canada and many other nations, the shutdown of coffee shops and western-style fast-food restaurants in China did contribute to the sharp reduction in the demand for milk and other dairy products during the pandemic. As a result, many Chinese dairy farms, especially small ones, could not sell their milk, causing some of them to dump their production. Dairy farms in Hubei Province, the center of the pandemic in China, could not sell up to 80% of the milk produced during the week after the lockdown of Wuhan and several other cities. For the dairy farms who could sell their milk, the price they received was significantly lower than the price prior to the pandemic. According to the State Council of China (2020), farmgate milk prices in China dropped 0.70% in February 2020 and 1.60% in March 2020. During the COVID-19 pandemic, many Chinese dairy processors processed a large amount of milk into milk powder and placed that into storage.

Third, many milk and dairy processing facilities were forced to shut down or operate at reduced capacity (Hua *et al.* 2020). The major reasons were reduced demand for their products, shortage of workers, overstock of inventories, disrupted transportation, and financial difficulties. Dairy

processing facilities in many regions were ordered to shut down by the local governments or could not meet the conditions for reopening the operations set by the governments. Although most of the dairy processing facilities in China reopened their operations in summer 2020, some of them have not yet returned to normal production levels.

While the above assessment is based on secondary data, the following analysis is based on primary data collected from a survey of 128 dairy farms in China. The survey was developed and conducted by three coauthors of this article and their colleagues at the Rural Development Institute of the Chinese Academy of Social Sciences, in collaboration with several other institutions. The major objectives of the survey were to assess how the COVID-19 pandemic had impacted different aspects of dairy farm operations and what actions the dairy farmers had taken to address problems such as surplus milk. The survey questionnaire was pretested with a small group of dairy farmers in mid-February, and the comments and suggestions from the farmers were incorporated in the revision. The survey was conducted online due to time and funding constraints. Mailing lists of dairy farms were compiled by the Rural Development Research Institute and its collaborating institutions, including the College of Economics and Management at the Inner Mongolia University, China. Dairy farmers from the lists were invited to complete the survey, and it was instructed that each farm should complete the survey only once in case more than one person from a farm received the survey invitation.

A total of 132 dairy farms responded to the survey during the period of February 20 to March 5, 2020. Data from 128 completed surveys were analyzed, and the results are presented in this paper (four farms did not complete the survey). While the 128 dairy farms were from 16 provinces and autonomous regions in China, 71.90% of them were from China's four large dairy provinces and autonomous regions (Hebei, Heilongjiang, Inner Mongolia and Shandong). Their herd sizes ranged from 10 cows to 10 600 cows. More detailed summary statistics of the 128 surveyed farms, not reported in this paper but available from the authors, suggest that most of the farms participating in the survey can be considered commercial dairy farms in China. The survey included only several very small farms with fewer than 20 cows. Considering that China's dairy industry has undergone rapid transition from household-based small operations to large commercial farms in the past two decades (Wang *et al.* 2010; PwC Network 2019; Wang and Zou 2020), data from the survey are a good representation of the commercial dairy farms that now dominate China's dairy industry.

As reported in Table 2, the survey asked questions

about the pandemic's disruption to three main areas of the supply chain and farm operations: (1) production and transportation, (2) sales of milk to processors, and (3) financial management.

For production and transportation, the top problems were increased price of feed and other inputs, reported by 69.53% of the farms, followed by insufficient supply of inputs (48.44%), insufficient labor availability (39.84%), difficulty of transporting milk (11.72%), and other transportation problems such as transporting the manure and culled cows (5.47%). Sales of milk to processors was also significantly impacted, with 86.72% of respondents reporting that they suffered from reduced price. In addition, 27.34% of the farms could not sell all of their milk, 6.25% of the farms had their milk refused by processors, and 12.50% of the farms had to dump some of their milk during the pandemic. Some farmers commented that they sold some milk at significantly reduced prices through middlemen, but still had to dump some milk. Respondents reported that dumped milk accounted for about 15% of their total output in February 2020, with some farms dumped up to 60% of their production.

Respondents also reported experiencing a variety of financial challenges due to the pandemic. The greatest challenge was the lack of operating capital (74.22%), followed by difficulties paying bills (46.88%), increase in debt (35.94%), difficulties borrowing money (29.69%), and increase in accounts receivable (12.50%). China's capital market has been under reform but is still highly controlled by the government and dominated by state-owned banks. It has been frequently reported that it is difficult for many farms and small businesses to obtain loans from large banks, and the situation worsened during the pandemic

Table 2 Impacts of the COVID-19 pandemic on the 128 surveyed dairy farms in China

Impacts	Number of dairy farms	Percent of the dairy farms (%)
Production and transportation		
Insufficient supply of inputs	62	48.44
Increased price of inputs	89	69.53
Insufficient labor availability	51	39.84
Difficulty of transporting milk	15	11.72
Other transportation problems	7	5.47
Sales of milk to processors		
Refused	8	6.25
Reduced quantity	35	27.34
Reduced price	111	86.72
Had to dump milk	16	12.50
Financial problems		
Lack of operating capital	95	74.22
Increase in debt	46	35.94
Difficulty of paying bills	60	46.88
Increase in accounts receivable	16	12.50
Difficulty of borrowing capital	38	29.69

when many banks were closed temporarily or provided service online only.

Farmers were also asked about the range of price reductions for their milk during the pandemic. The results are reported in Fig. 1. As compared to the milk price they received from the processors prior to the pandemic, 86.73% of the surveyed farms received a lower price for their milk during the pandemic. The reduction in milk price ranged from less than 10% for 31.25% of the farms to more than 50% for 3.13% of the farms.

Data reported in Fig. 1 support the secondary data's finding that the COVID-19 pandemic resulted in a significant reduction in farmgate milk price. As to be discussed in the next section, the average milk price received by Chinese dairy farms has been significantly higher than that received by U.S. farms, but milk yield per cow in China is significantly lower than that in the United States. To examine the variation in the COVID-19 pandemic's impacts across farm groups, the surveyed farms are divided into three groups according to herd size: Fewer than 500 cows, 500–1 000 cows, and more than 1 000 cows. The results presented in Table 3 suggest four major findings. First, a relatively larger proportion of larger farms experienced worker shortages and milk transportation problems during the pandemic. This was likely due to a greater need for more skilled workers, and the production of larger quantities of milk requiring more transportation than that for smaller dairy farms. Second, as compared to farms with fewer than 500 cows, a larger proportion of larger farms reported the problem of insufficient supply of feed and other inputs. Third, proportionally fewer larger farms experienced problems selling their milk, likely due to long-term contracts with their processors, but about the same proportion of the farms received lower prices for their milk across the three groups. Among the dairy farms forced to dump milk, about three-fourths of them were in the group with fewer than 500 cows. Farms with fewer than 500 cows dumped an average of 20% of their milk, while farms with 500–1 000 cows dumped an average of 10% of their milk and farms with more than 1 000 cows dumped only 3% of their milk. Fourth, regarding the financial aspects, smaller proportions of the larger farms experienced problems obtaining operating capital, increased debts, and difficulty paying the bills and securing loans. Compared to their financial performance prior to the pandemic, all the surveyed dairy farms lost an average of 476 CNY per cow, with the smaller dairy farms experienced significantly more losses.

The survey also asked questions regarding actions taken by dairy farms to reduce their milk production in the pandemic. The results, reported in Table 4, suggest two major findings. First, respondents reported the leading action for reducing milk production was "early dry off" (38.28%). A greater proportion of smaller farms took

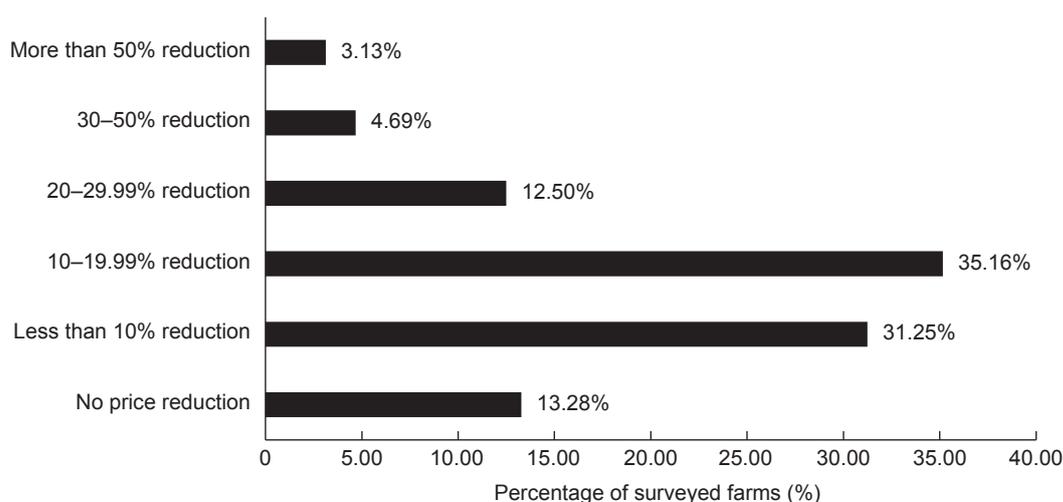


Fig. 1 Reduction in milk price received by the surveyed farms during the COVID-19 pandemic.

Table 3 Impacts of the COVID-19 pandemic on different farms by herd size in China (%)

Impacts	Fewer than 500 cows	500–1 000 cows	More than 1 000 cows
Production and transportation			
Insufficient supply of inputs	36.36	55.81	53.66
Increased price of inputs	68.18	74.42	65.85
Insufficient labor availability	34.09	41.86	43.90
Difficulty of transporting milk	9.09	9.30	17.07
Other transportation problems	4.55		12.20
Sales of milk to processors			
Refused	11.36	4.65	2.44
Reduced quantity	34.09	30.23	17.07
Reduced price	88.64	88.37	82.93
Had to dump milk	20.45	7.00	9.76
Financial problems			
Lack of operating capital	81.82	79.07	60.98
Increase in debt	45.45	32.56	29.27
Difficulty of paying bills	61.36	48.84	29.27
Increase in accounts receivable	6.82	16.28	14.63
Difficulty of borrowing capital	36.36	25.59	26.83

this action, likely due to their difficulty in selling milk. It can also be noted that early dry off may be the simplest method to implement. Other actions include “reformulate feed” (35.16%), “limit feeding” (31.25%), and “early culling” (28.91%). Second, proportionally fewer larger dairy farms reduced feed to reduce milk production as compared to smaller farms. The likely reasons include that the larger dairy farms are more concerned about the long-term impacts of feed management and may also have more capacity to have their surplus milk processed into milk powder for inventory.

While China is a huge country, the survey data can be analyzed to assess the differences across regions in both the pandemic’s impacts and the actions taken by farms. For example, among the major dairy regions, significantly

more dairy farms in Inner Mongolia (54.50%) reported increased debts than their counterparts in Hebei (35.50%) and Heilongjiang (22.20%) provinces. Similarly, 59.10% of the surveyed dairy farms in Inner Mongolia reported difficulties paying bills, as compared to 51.50% in Hebei and only 37.00% in Heilongjiang. The differences in financial difficulties across regions were likely due to the variation in programs and support offered by the provincial and local governments and financial institutions. Regarding the actions to reduce milk production during the pandemic, the surveyed farms in Heilongjiang were more likely to adjust feeding, and farms in Hebei were more likely to adjust their herds. For example, 48.39% of the farms in Hebei adopted early dry off and 32.26% of them adopted early culling, as compared to the corresponding proportions of only 7.41 and

Table 4 Actions taken by surveyed dairy farms to reduce milk production (number and percentage of farms)

Farm size	Early dry off	Early culling	Limit feeding	Reformulate feed
All 128 surveyed farms	49 (38.28%)	37 (28.91%)	40 (31.25%)	45 (35.16%)
44 farms with fewer than 500 cows	21 (47.73%)	14 (31.82%)	16 (36.36%)	14 (31.82%)
43 farms with 500–1 000 cows	15 (34.88%)	14 (32.56%)	14 (32.56%)	17 (39.54%)
41 farms with more than 1 000 cows	13 (31.70%)	9 (21.95%)	10 (24.39%)	14 (34.15%)

11.11% in Heilongjiang, respectively.

3.2. Impacts of the COVID-19 pandemic on the dairy industry in the United States

Although the United States has one of the most efficient and reliable farm-to-market food systems in the world, its food system for dairy and many other products suffered from unprecedented disruptions and uncertainty due to COVID-19. With a total milk production of 218.3 billion pounds, or an average of 23 400 pounds per cow in 2019 (USDA 2020), the United States is the largest and most productive milk producer in the world. There are four major final destinations for milk and other dairy products, like cheese and butter, produced in the United States: (1) households *via* grocery stores and online purchase, (2) schools through government-subsidized purchase and colleges through institutional purchase, (3) restaurants, hotels, and other businesses and organizations *via* bulk purchase, and (4) foreign markets *via* exports.

For the purchase of milk and other dairy products by individual households, sales increased sharply when the “stay at home” orders were issued. In the early stages of the pandemic, many consumers rushed to grocers to buy and store more food at home, resulting in empty shelves in many grocery stores in mid-March. Purchases of milk and other dairy products, like ice cream and yogurt, then decreased significantly when many households started to order food online. From a practical perspective, milk and most dairy products are difficult to purchase online for home delivery. Different from many consumers in Europe and Asia who drink UHT-processed milk that does not require refrigeration, American consumers have traditionally drunk only cold milk because UHT milk is not culturally accepted and, as a result, not prevalent in the marketplace in North America.

In mid-March 2020, demand for milk and other dairy products dropped by as much as 50% in some regions due to the “stay at home” or “shelter in place” orders for mitigating the pandemic. The nationwide shutdown of educational institutions, restaurants, hotels, and many other businesses were some of the major reasons for this reduction in demand. In the United States, many dairy processors and cooperatives have been powdering and storing milk powder for the past several years and, when

surplus milk increased sharply due to this pandemic, they simply could not store more milk powder.

The significantly reduced demand for bulk purchases also resulted in huge problems for many processors with processing lines designed for only these bulk destinations. For example, some milk processors are able to process and pack milk in small containers for schools and hotels, whereas it was either impossible or cost-prohibitive to process and pack milk for grocers or food banks. On the other hand, some processors have designed their processing lines to process and pack cheese and other dairy products in large quantities, and it is similarly difficult and expensive for them to process and pack milk and other dairy products for groceries (BBC News 2020).

As a result of the sudden decrease in demand for milk, many U.S. dairy farmers had to dump their milk due to storage, shipping, and processing limitations. For example, it was estimated that about 5% of the country’s milk output in April 2020 was dumped, and the percentage was likely higher in May 2020 (Yaffe-Bellany and Corkery 2020). As discussed in the introduction, many dairy farms around the world had to dump milk during the pandemic.

The United States exports approximately 15% of its milk solids to other nations, including Mexico, Canada, China, South Korea, and Japan. Although the pandemic has caused disruptions in international trade and transportation, U.S. exports of dairy products increased significantly during January to May 2020 in terms of the total value and aggregate volume compared to the same period in 2019. The majority of the growth came from increased shipments of nonfat dry milk and skim milk powder to Southeast Asia and whey products to China (U.S. Dairy Export Council 2020). Although the increase in U.S. exports of dairy products since January 2020 has helped to offset the pandemic’s impacts on its dairy industry, many U.S. dairy farms have been struggling to stay in business due to low farmgate milk price.

The monthly farmgate milk price, forecasted by different dairy cooperatives and organizations, is one of the most important indicators for the future health of the dairy industry in the United States. The forecasted monthly prices for 2020 were adjusted every month in spring 2020 into lower levels due to the impacts of the COVID-19 pandemic. As shown in Fig. 2, the monthly Boston blend milk prices forecasted by Agri-Mark for February to December 2020 were lowered by

4.40 to 11.16% in its forecasts published on February 28 as compared to that published on January 22, the forecasted monthly prices for March to December 2020 were lowered again by 3.91 to 11.73% in the forecasts published on March 24 and, in its forecasts published on April 21, the forecasted monthly milk prices for April to December 2020 were lowered again by 9.67 to 24.91%. Compared to the forecasts published on January 22, the forecasted milk prices for April to December 2020, published on April 21, were lowered by 21.43 to 39.68%. The above changes in the forecasts published from January to April 2020 were a good indication of the pandemic's heavy impacts on the dairy industry in the United States.

In the United States, the farmgate prices for milk are based on how the milk is utilized among four different destinations: Class I covers milk used for fluid or beverage milk products and receives the highest price, Class II refers to milk going into "soft" manufactured products such as sour cream, cottage cheese, ice cream, and yogurt, Class III includes milk used for making hard cheeses, and Class IV milk is used to make butter and dry products such as non-fat dry milk (NFD) and receives the lowest price (IDFA 2019). The blend prices presented in Fig. 2 are based on usage of milk within each of the four main classes and the hundredweight prices of each class.

Although many U.S. dairy farms, especially small and medium farms, have been struggling with low and fluctuating milk prices and increasing production costs for many years, the observed price decrease in spring 2020 and the forecasted decrease for the remainder of the year will likely force additional dairy farms out of business if the

demand for milk and other dairy product does not recover quickly. These COVID-19 dairy market disruptions highlight the ongoing trends of low adoption of risk management strategies in place on U.S. dairy farms. For example, less than half of U.S. milk is covered under the Dairy Margin Coverage and Dairy Revenue Protection programs (Natzke 2020). Farm owners that did enroll in these programs or purchased other risk management products anticipate receiving compensation to mitigate portions of the losses incurred in early 2020.

Some financial assistance from the federal government such as low-interest loans and direct payment programs began to be offered in early summer 2020. Many state and local governments and industry-related organizations have also made great efforts to help dairy farms, but dairy producers and industry experts alike worry that it may be too late to save some dairy farms. For example, in the state of Vermont, significant funds have been raised to transport surplus milk from local dairy farms to local dairy processors and then donate milk and cheese to area foodbanks. Such ongoing efforts are helping a small number of dairy farms, but most farms are nonetheless struggling to survive.

The United States had a total of 37 468 licensed dairy farms as of March 2019 (USDA 2020). The number of licensed dairy farms has been decreasing for many years due to the oversupply of milk production and fluctuating milk price. For example, the number of dairy farms in the state of Vermont, a major dairy production state in the northeastern United States, decreased steadily from 1 015 in 2010 to 677 in 2019, and is likely to be fewer than 600 by the end of 2020, partially due to the economic effects of

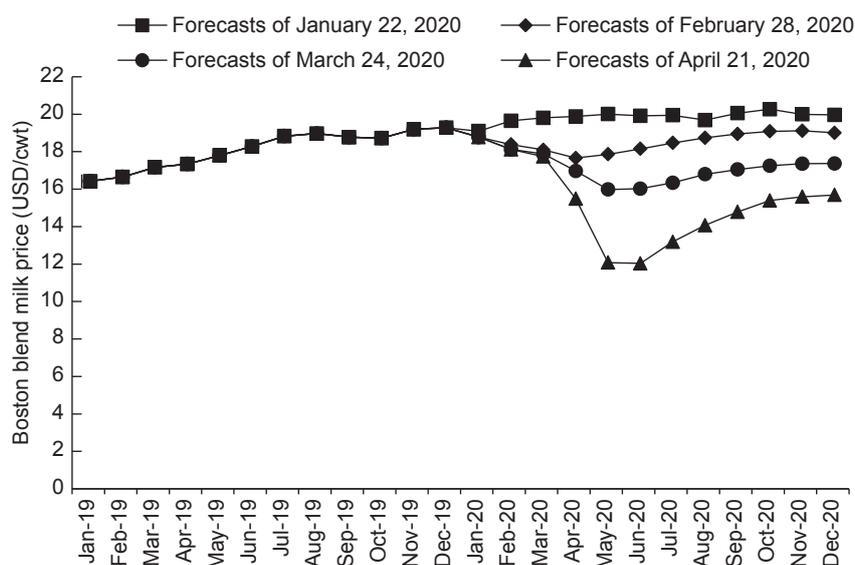


Fig. 2 Agri-Mark forecasts of Boston blend milk price for 2020. cwt, hundredweight. Source: Agri-Mark Dairy Cooperative (2020).

the COVID-19 pandemic. A 2019 survey of small farms in Vermont, prior to COVID-19, found that 71% of farms were uncertain of their short-term outlook and 42% were likely to consider a business exit in the next five years (Cannella and Kitsos 2020). On the other hand, Vermont's total milk production increased steadily, from 2.50 billion pounds in 2010 to 2.70 billion pounds in 2019. The entire dairy industry has struggled as a result of the increasing milk production and fluctuating price, with no simple solution to the problem. The COVID-19 pandemic has now brought about additional challenges to the dairy industry in the United States.

3.3. Comparison of the pandemic's impacts on the dairy industries in the two nations

The dairy industry in China is significantly different from that in the United States, especially in the areas of commercialization, productivity, integration, feed management, and international trade. It is of significant interest to analyze and compare how the dairy industries in both countries have been impacted by the COVID-19 pandemic. Such information and lessons learned from the two nations can be useful for developing strategies

to enhance the resiliency and sustainability of the dairy industries in the two nations and around the world.

Because primary data from the United States are very limited, findings on the similarities and differences reported in Table 5 are largely based on assessment by the authors with inputs from several experts on the dairy industries in the two nations.

As summarized in Table 5, both nations' dairy industries were heavily impacted by the pandemic through similar mechanisms, such as reduced milk demand and price due to closed schools, colleges, restaurants and hotels. Also, reduced labor availability for dairy farms in spring 2020 was widely reported in both nations. On the other hand, there were some significant differences in how the pandemic affected the dairy industries in the two nations. For example, as part of China's strict government measurements for stopping the spread of the coronavirus, many roads were blocked from late January to mid-March. As a result, many of China's dairy farms simply could not access the necessary distribution and transportation for feed and milk. In contrast, although the slow overall government response to the coronavirus impacts in the United States have been criticized, the country did reasonably well in

Table 5 Comparison of the pandemic's impacts on the dairy industries in the United States and China¹⁾

Impacts and mechanisms	The United States	China	Comments
Milk production			
Feed supply	↓	↓↓	Milk production in China was affected for a shorter period of time than in the United States, and the recovery has made great progress since late March 2020
Feed costs	↑	↑↑	
Labor supply	↓↓	↓↓↓	
Labor costs	↑	↑↑	
Difficulty of milk transportation	–	↑↑	
Milk price	↓↓↓	↓↓	
Actions to reduce output			
Early dry off	↑	↑↑	
Early culling	↑	↑↑	
Limit feeding	↑	↑↑	
Change feeding mix	↑	↑↑	
Dairy processing			
Labor supply	↓↓	↓↓	
Labor costs	↑	↑↑	
Transportation difficulty	–	↑↑	
Problems of inflexibility	↑↑↑	↑	
Demand and trade			
Households <i>via</i> groceries	↓	↓↓	In China, milk is a major gift product and the purchase of dairy by schools, restaurants, and hotels is relatively limited
Households online	↑	↑	
As gifts		↓↓↓	
Schools and colleges	↓↓↓	↓↓	
Restaurants	↓↓↓	↓↓	
Hotels	↓↓↓	↓↓	
Exports	↑	–	China's exports are very limited
Imports	↑	↑↑	
Government assistance	Yes	Yes	

¹⁾ ↓, minor decrease; ↓↓, significant decrease; ↓↓↓, very significant decrease; ↑, minor increase; ↑↑, significant increase; ↑↑↑, very significant increase; –, limited change.

keeping the distribution networks functional and keeping essential businesses in operation. Institutional demand for dairy products is significantly different in the two countries. The United States uses much more milk and milk products in public schools than China. While schools in the United States normally provide 29.8 million lunches each school day, with 20.2 million of those free to students and paid for by the government, their closing during the pandemic had significant impacts on the demand for milk and other dairy products. Also, many dairy processors had to shut down their operation because their processing lines were designed to process products for the schools. Although many schools in China also offer school lunch programs, the scale and impacts on milk demand are much smaller than in the United States.

4. Discussion

COVID-19 is an unprecedented pandemic and has exposed the strengths and weaknesses of the food systems in both the United States and China (Chen *et al.* 2020). This study outlines five key lessons and corresponding policy implications that are based on our comparative analysis of how the pandemic has impacted the dairy industries in the two nations.

First, while the Chinese government's slow response to the COVID-19 pandemic in January 2020 was widely criticized by the U.S. government and media, all the problems reported in China in January and February 2020 with testing, reporting, the lack of personal protective equipment (PPE), and surplus milk and many other farm products were also repeated in the United States, and to an even worse degree in many regions. The pandemic challenged dairy farmers and processors in China and the United States with many similar problems. It is very likely that this pandemic will continue to disrupt dairy and other industries around the world, and that other pandemics may have similar negative impacts on the dairy industry and other agricultural sectors in the future. Each country and industry must consider the potential of repeat or new supply-chain disruptions in their development plans, investment, and budgeting. For example, dairy farmers in some areas of China were able to haul their milk to processing facilities and process it into milk powder for storage in the pandemic, whereas few dairy farms in the United States had that option. Dramatic market downturns from episodic oversupplies of milk have plagued the dairy industry in the United States for many years. The negative effects of the pandemic may encourage dairy farm cooperatives to develop detailed plans about how to deal with surplus milk when farmgate prices are too low, or when a pandemic or natural disaster happens. For example, large dairy cooperatives may invest in processing facilities to

process fluid milk into milk powder, and they may increase their storage capacity for these products. In China, where small dairy farms suffered much more than larger farms, the pandemic may accelerate the ongoing transition from small farm operations with few cows, to large commercial operations with higher productivity, and better quality and safety control (PwC Network 2019; Wang *et al.* 2020). Also, while China's experience suggests that the central government should offer more flexibility to provincial and local governments to adopt measurements of controlling the spread of the virus, the experience in the United States may suggest that there should be more consistency across all states and regions. For example, there was only one confirmed COVID-19 case in Tibet, but a quarantine was implemented in Tibet similar to that in Hubei. Also, it was not reasonable for many villages and communities in China to block roads and access to highways, causing transportation problems for farms and other businesses.

Second, this pandemic has exposed many weaknesses of the food system in the United States. Based on highly integrated supply chains, the food system is generally considered to be both modern and efficient in providing abundant choices of high-quality food products at prices significantly lower than those in many other nations. However, a major problem of the food system is the tradeoff between high efficiency and low flexibilities. For example, this pandemic caused significant food waste such as dumped milk, smashed eggs, and plowed vegetables in spring 2020 (Yaffe-Bellany and Corkery 2020). Also, many high-efficiency milk processing facilities that were designed to process milk for school consumption only had to shut down when the schools were closed even though there were surplus milk and strong demand from retailers. The dairy situation highlights the incongruous nature of food systems that facilitate not only the flow of fresh, raw, or lightly processed food products to regional consumers but also commodity component based enterprises that rely on more complex chains of processing, transportation, and international trade. In 2020, short-term retail milk shortages occurred simultaneously with milk dumping, production quotas, processing infrastructure overloads and farm-gate payment reductions. Some processors also had to shut down due to illness among plant workers.

While alternative local and regional food systems have received increased attention across the United States in recent years, this pandemic may encourage policymakers, food industry leaders, food retailers, farmer cooperatives, and communities to reevaluate "supply chains in the middle," much like "agriculture in the middle" necessitates more attention. Policy, programs, and entrepreneurs will need to fill the large space between divergent industrial food chains and hyper-local marketing initiatives. The former

could stand to improve supply management mechanisms to moderate overproduction and prepare for swifter market adjustments, while the latter will need to improve processing capacity and distribution efficiencies to increase reach into broader market segments. For example, when many food processing companies had to shut down during this pandemic, many local dairy processors experienced significant increases in sales, mainly through online sales (Donaldson 2020).

As a large economy under ongoing transition toward market systems, China has moved gradually in adopting the food systems developed in the United States and other industrial nations. As shown in Table 1, more than 35% of China's total dairy product consumption, in terms of milk-equivalent weight, was imported from the United States and several other nations in 2019. This pandemic may encourage China to increase investments in its relatively young dairy industry and slow down its participation in economic globalization. China should also learn from the successes and failures of the highly efficient food systems developed in the United States and other nations.

Third, as shown in Table 1, the small market share of UHT pasteurized milk in the United States was likely a contributing factor to the dairy market problems in the early stages of the pandemic, which could be attributed to a lack of consumer acceptance in the United States and Canada due to the traditional belief that milk has to be cold. UHT milk has been widely accepted in China and many European nations such as France. This pasteurization technique provides for long shelf life of up to several months without refrigeration during transportation, in storage or at home. If UHT milk indeed has the same quality and health benefits as cold milk, the dairy industry in the United States should broaden its efforts to increase consumer acceptance of UHT milk, reducing the costs and increasing the convenience of milk consumption. Similar to the evolution of butter and cheese inventory strategies, a shift to UHT fluid milk could provide an additional inventory management strategy that reduces volatility in fluid milk supply chains. As shown in Table 1, the annual per capita cheese consumption in China is less than 0.1 kg as compared to more than 18 kg in the United States. A small increase in the per capita consumption of cheese in China may bring about a significant increase in the demand for milk due to the country's huge population. It is important to identify the reasons why so many Chinese consumers dislike cheese and then develop strategies to change consumer preferences.

Fourth, another major problem in the U.S. food system exposed by this pandemic is the fact that more than 20 million school students rely on free school lunches and experienced food access problems when their schools were closed. To meet the basic nutritional needs of these

students, especially those from families in poverty or with parents who lost jobs due to the pandemic, many school districts across the country chose to continue to serve or deliver lunches to these students while their schools were closed. Also, many people rushed to foodbanks and other charity organizations for food assistance. These problems in the United States are largely due to its lack of progress in poverty reduction over many years. In contrast, China's progress in poverty reduction in the past decade paid off during this pandemic—there were very limited reports about families who could not afford or obtain enough food during the nationwide quarantines. This was largely due both to the significant reduction in poverty as a national economic development goal for more than 10 years and to a well-established system for local government and communities to take responsibility for helping families with low income. Although there is no simple or easy solution, the United States must make more efforts to reduce poverty and income inequality. A reduction in poverty would greatly increase resilience in the face of pandemics and natural disasters.

Fifth, the United States has developed many piecemeal policies affecting the dairy sector but has not solved the fundamental problem of milk oversupply. As a result, the dairy sector, especially dairy farms, has been struggling with low and fluctuating milk prices and increasing production costs for many years. Either expanding demand through consumer education and increasing exports, reducing production as Canada has done or both, would enhance the health and resilience of the dairy sector. By 2019 (before COVID-19 disruptions), after four years of sustained low milk prices, an increasing number of regional dairy communities formerly opposed to market management efforts were openly discussing supply management mechanisms to promote more stable farmgate prices. As shown in Table 1, with China as the world's largest dairy importer and the United States as the fourth largest dairy exporter, there are great potentials for the two nations to benefit from trade and collaboration. While it is uncertain how this pandemic will affect the ongoing trade disputes and retaliations that started in early 2018 (Wang and Zou 2020), the dairy industries in both nations should make efforts to increase collaboration and trade to enhance the resilience of domestic dairy markets.

5. Conclusion

While the COVID-19 pandemic has heavily impacted dairy industries around the world and there have been limited studies on these impacts, this study has assessed the pandemic's impacts on the dairy industries in China and the United States, analyzed and compared the mechanisms through which the pandemic has affected the dairy

industries in the two large dairy nations, discussed potential lessons from the pandemic experience, and derived policy recommendations for improving the resilience and sustainability of the dairy industries. This study suggests that the pandemic has heavily affected the dairy industries in both nations through many similar mechanisms but there are also significant differences between the two nations. The potential lessons learned from the United States and China and the corresponding policy recommendations discussed in this paper are expected to be helpful for developing policy interventions and industrial strategies to enhance the resilience of the dairy industry in future pandemics and other market shocks in China, the United States, and many other nations.

Similar to many other studies on the impacts of the COVID-19 pandemic, this study is highly limited by the data availability. First, our analysis of the impacts in China was based on both secondary and primary data from an online survey of dairy farms, but the analysis of the impacts in the United States was based on only secondary data. Second, the comparative assessment of how the pandemic affected the dairy industries in China and United States, reported in Table 5, was largely based on qualitative analysis using secondary data and inputs from several dairy experts in the two countries. Third, the analysis presented in this paper focused on the pandemic period through the end of May 2020 and does not cover the market changes and the impacts of government policy interventions since June 2020. For example, in the state of Vermont, the state government announced 25 million USD in relief grants for dairy farmers and processors in July 2020, but it remains too early to assess the impacts of the grants on the state's dairy industry (SVAAFM 2020).

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