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Structure, Costs, and Technology Used on U.S. Dairy Farms

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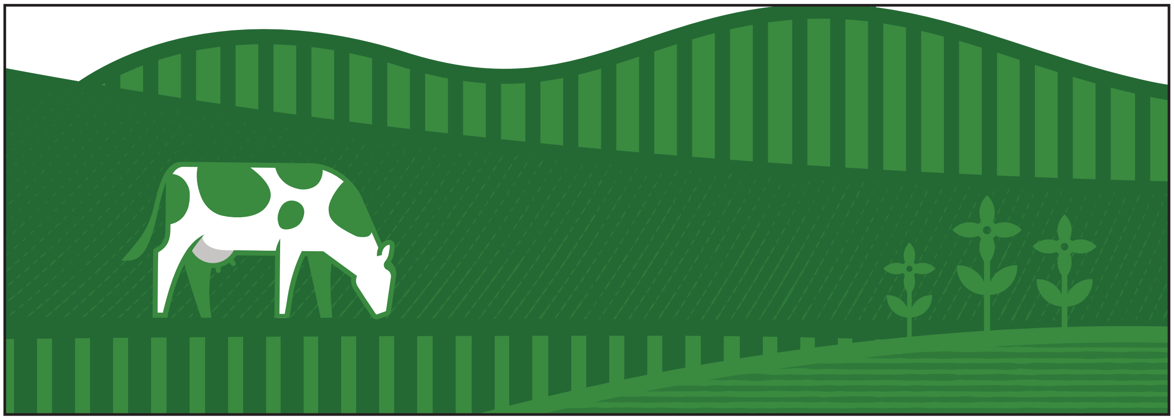

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Abstract

The milk production segment of the U.S. dairy industry has experienced significant change over the past two decades. Various USDA data sources allow for analysis of how dairy farms have changed in structure and production costs. This study uses USDA's Agricultural Resource Management Survey (ARMS) dairy version data from 2000, 2005, 2010, 2016, and 2021 (and other USDA data) to examine changes in farm structure, production costs, and technology adoption and to compare dairy farms by size and production region over the past two decades. Methods used to analyze the data include the difference in means tests and stochastic frontier analysis. Dairy farm numbers have decreased, while milk production has increased; increases in the use of some advanced farm technology have occurred; larger farms benefit from economies of scale and are the greater users of advanced technologies and production systems; and there are regional differences in farm structure and cost of production.

Keywords: dairy sector, milk production, dairy farms, dairy herd size, commodity costs and returns, technology adoption, farming, cost of production

About the Authors

Jeffrey Gillespie, Eric Njuki, and Angel Terán are economists with USDA, Economic Research Service.

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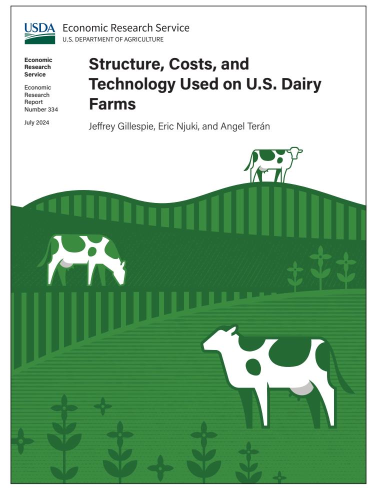


What Is the Issue?

Over the past two decades, the U.S. dairy industry has evolved, with fewer dairy farms producing more milk. This raises questions about how dairy farms have changed in size, diversification, location, use of advanced technology, and cost of production. Questions also arise about economies of scale in the dairy industry and the structure of larger versus smaller dairy farms. Shifts in the location of milk production lead to questions about how dairy farm size, diversification, use of technology, and cost of production differ by U.S. region. This report addresses issues of how the dairy farm structure has changed over the past two decades and how the structure differs by size of the operation and by U.S. region.

What Did the Study Find?

Highlights of study findings include:

- Consistent with long-term trends, the number of U.S. dairy farms has fallen (while milk production has risen), with larger dairy farms emerging that produce more milk per cow. The number of farms with fewer than 1,000 cows has fallen, while the number of farms with 1,000 or more cows has risen over the past two decades.
- Moderate shifts in the location of dairy farms occurred between 2002 and 2022, with Texas and Idaho gaining production share and California losing production share.
- Dairy farm usage has trended upward for several advanced technologies, management practices, and production systems: automatic take-offs, computerized milking systems, use of a milking parlor, and milking cows three or more times daily. The use of bovine somatotropin (bST) has decreased.
- Over the period 2000–22, the average U.S. dairy farm covered operating costs in most years, operating and ownership costs in about half of the years, and total economic costs in only 2 years.
- Relative to smaller dairy farms (those with fewer cows), larger dairy farms in 2021, on average: (1) were more specialized in dairy production; (2) were greater adopters of most advanced technologies, management practices,

and production systems; (3) had lower total costs per unit of milk sold (due primarily to lower ownership costs of buildings and equipment, and lower unpaid labor costs); (4) had higher purchased feed costs, lower homegrown feed costs, and lower grazed feed costs per unit of milk sold; and (5) had higher paid labor costs relative to unpaid labor costs per unit of milk sold.

- In 2021 (relative to eastern U.S. dairy farms), western U.S. dairy farms: (1) were generally larger, more specialized in dairy production, and more likely to use advanced technologies, management practices, and production systems; (2) on a per unit of milk sold basis, tended to incur lower ownership costs and lower total economic costs; and (3) depended more on purchased feeds and less on homegrown feeds.

How Was the Study Conducted?

This study relies on data from several sources, primarily the USDA's Agricultural Resource Management Survey (ARMS) and various agricultural data sources reported by the USDA, National Agricultural Statistics Service (NASS). The five most recent ARMS dairy surveys (2000, 2005, 2010, 2016, and 2021) allow for analysis of costs and returns, farm structure, and the adoption of various technologies, management practices, and production systems on dairy farms over the past two decades. The study reports on primarily farm-level means (using ARMS data), with differences in means tests conducted using the delete-a-group jackknife procedure. Econometric estimation of cost functions to further examine economies of scale and farm efficiency uses stochastic frontier methodology. Separate cost functions are run for different farm size categories, as well as a model including all farm sizes.

Structure, Costs, and Technology Used on U.S. Dairy Farms

Introduction

Over the past 90 years, the number of U.S. dairy farms has declined dramatically—while dairy farm size and the use of advanced technologies, management practices, and production systems have increased. The number of farms with milk cows decreased from 5.2 million in 1934 to 36,024 in 2022 (USDA, NASS Census of Agriculture, 2022), while milk production increased from 101.6 billion pounds in 1934 to 226.4 billion pounds in 2022 (USDA, NASS, 2024). In short, fewer, larger farms produced more total milk. Dairy farms, however, continue to vary widely in size and the use of technology, management practices, and production systems, and these farms continue to operate under a wide range of production conditions. The February 2023 USDA, National Agricultural Statistics Service (NASS) Milk Production report shows that there was at least a single licensed dairy herd[1] in every U.S. State in 2022, with Wisconsin having the greatest number of farms (6,350) and California having the greatest milk production. In this report, the authors describe how U.S. dairy production has changed over the past two decades regarding milk production, farm size, costs and returns (CAR) associated with milk production, efficiency, and the use of advanced technologies, management practices, and production systems. The authors further show how, in 2021—the year of the most recent Agricultural Resource Management Survey (ARMS) dairy data—dairy farms of different sizes and regions of the United States compared with each other in terms of farm structure, CAR, and technology usage.

Data Used in the Study

Data used in this study are from the USDA's ARMS dairy version; USDA, NASS, Census of Agriculture; and other USDA, NASS sources. The ARMS (conducted annually by USDA, Economic Research Service (ERS), and USDA, NASS) surveys U.S. farms to gather information on farm and farm household economic indicators and the use of farm production practices. Periodically, targeted ARMS questionnaires are sent to dairy producers to collect information specific to milk production, allowing for the development of milk CAR estimates and a determination of dairy farm characteristics. Dairy farms were targeted in the 2000, 2005, 2010, 2016, and 2021 ARMS. Dairy ARMS data are used for numerous USDA, ERS data products and publications, including commodity CAR estimates; reports concerning dairy CAR, industry structure, and farm production characteristics (Short, 2004; MacDonald et al., 2007; McBride & Greene, 2009; MacDonald et al., 2016; MacDonald et al., 2020; Njuki, 2022); and other publications covering dairy industry costs and structure, such as in peer-reviewed journals.

The number of U.S. States included in each ARMS dairy version has changed based on shifts in the industry structure, with dairy producers surveyed in 22, 24, 26, 28, and 28 States in 2000, 2005, 2010, 2016, and 2021, respectively.[2] For each year, these States have included at least 90 percent of the U.S. milk production on dairy farms, with at least 10 milk cows in inventory at some point during the year. Weights included in

[1] USDA, NASS Milk Production reports the number of dairy farms that are licensed to sell milk "based on counts collected from State and other regulatory agencies." Some farms with milk cows may not be licensed to sell milk. The February 2024 report shows the number of dairy farms in 46 States and 15 farms in the 4 remaining States. The data do not indicate whether each of the remaining States had dairy farms in 2023.

[2] States included in the 2000 survey were Arizona, California, Florida, Georgia, Idaho, Illinois, Indiana, Iowa, Kentucky, Michigan, Minnesota, Missouri, New Mexico, New York, Ohio, Pennsylvania, Tennessee, Texas, Vermont, Virginia, Washington, and Wisconsin. For 2005, Maine and Oregon were added. For 2010, Colorado and Kansas were added. For 2016 and 2021, South Dakota and Utah were added.

the data allow the sample to be extended to represent at least 90 percent of U.S. milk production on farms with at least 10 milk cows.

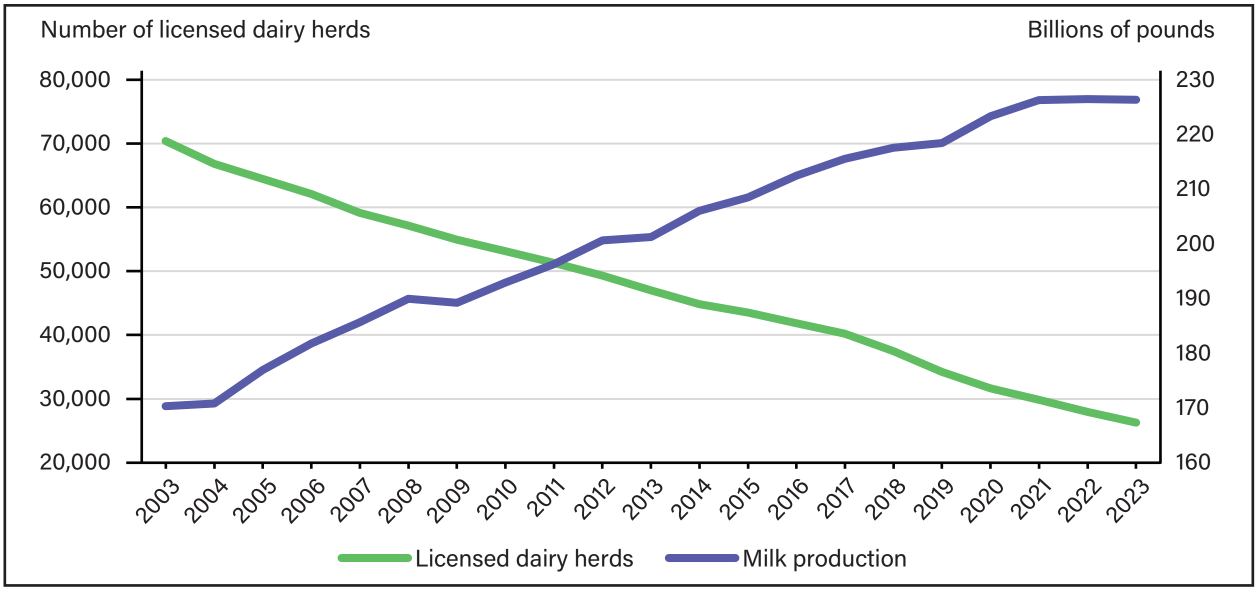
Criteria for inclusion in the ARMS differ from other surveys conducted by USDA, NASS. The U.S. Census of Agriculture reports farm numbers, characteristics, and production, with the most recent Census of Agriculture conducted in 2022. USDA, NASS collects additional information on U.S. agriculture via various surveys. Most USDA, NASS datasets include farms with at least $1,000 in sales, so these datasets include some farms with fewer than 10 milk cows. According to USDA, NASS, Census of Agriculture data, of the 24,082 dairy operations with milk sales in 2022, 22,613 (or 94 percent) were farms with 10 or more milk cows.

Structural Change in U.S. Milk Production

U.S. milk production has continued to increase over the past two decades as dairy farm numbers have declined. From 2003 to 2023, U.S. milk production increased from 170.3 billion pounds to 226.4 billion pounds, an increase of 33 percent over the two decades (figure 1). The number of dairy herds licensed to sell milk, however, declined from 70,375 in 2003 to 26,290 in 2023, a decrease of 63 percent. It is noted from figure 1 that there was an approximate linear decline in farm numbers rather than a constant rate of decline. For example, there were 18 percent fewer licensed dairy herds in 2008 than in 2003 and 30 percent fewer licensed dairy herds in 2023 than in 2018. The increase in milk production and decrease in the number of dairy herds are consistent with progressively larger farms and increased milk cow productivity over the period. The average number of pounds of milk produced per cow per year by U.S. dairy cows increased from 18,759 in 2003 to 24,117 in 2023, an increase of 29 percent (figure 2). Increased cow productivity can generally be attributed to the adoption of advanced technologies, management practices, and production systems and advancements in breeding herd genetics.

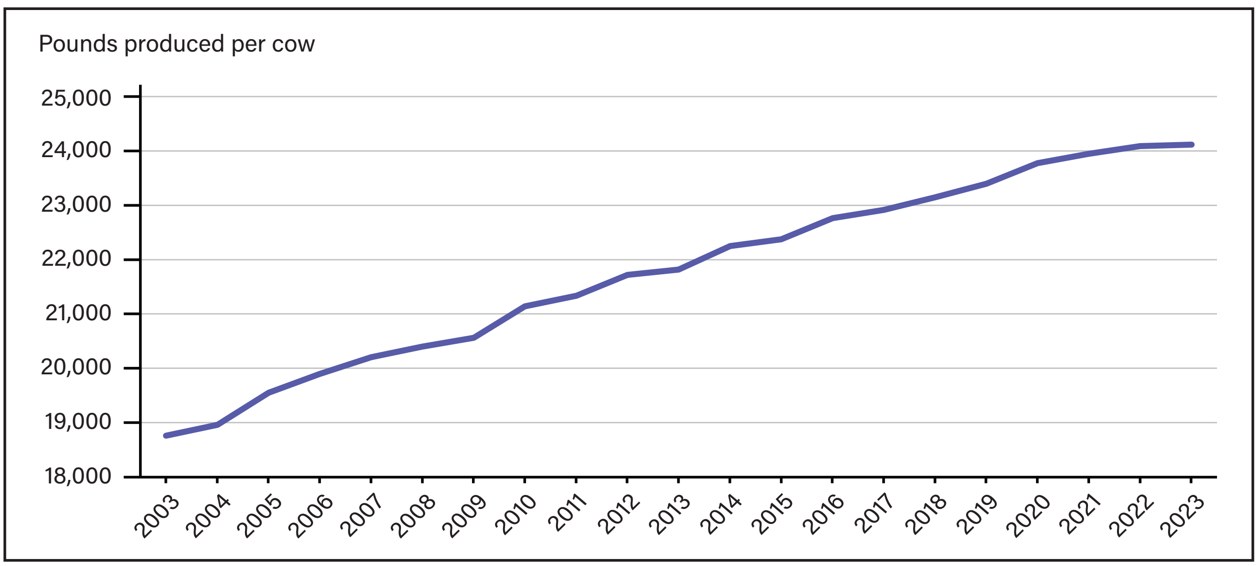
Increased dairy farm size is illustrated in figures 3 and 4, which show the numbers of U.S. dairy farms in each of the six different farm size categories. During the 21-year period from 2002 to 2022, dairy farm numbers declined in farms with sizes of 1–49 cows, 50–99 cows, 100–199 cows, 200–499 cows, and 500–999 cows. Farm-size classes decreased by 79 percent, 76 percent, 62 percent, 19 percent, and 13 percent, respectively. In contrast, the number of dairy farms with 1,000 or more cows increased by 60 percent. Larger dairy farms have generally benefited from a lower cost per unit of milk produced and have been greater adopters of advanced technologies, management practices, and production systems, as further analyzed in this report.

Figure 1
U.S. milk production, billions of pounds, and number of licensed dairy herds (2003–23)



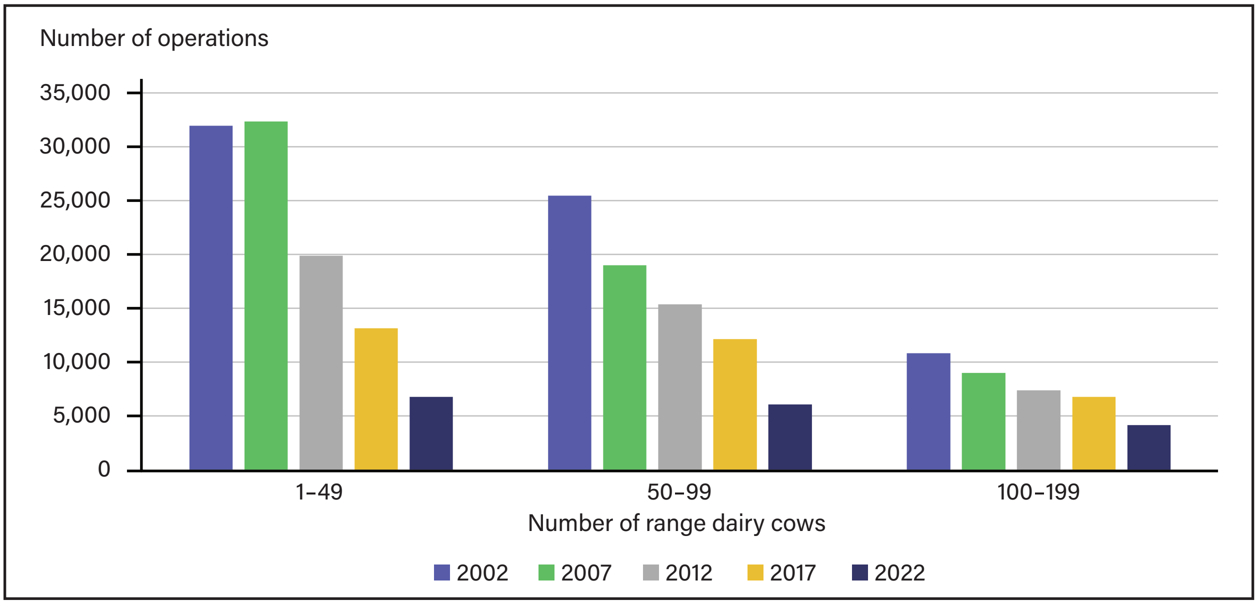
Source: USDA, Economic Research Service using data from USDA, National Agricultural Statistics Service, Milk Production, February issues 2005–18, March 2019, February 2020–24.

Figure 2
Pounds of milk produced per cow per year, 2003–23



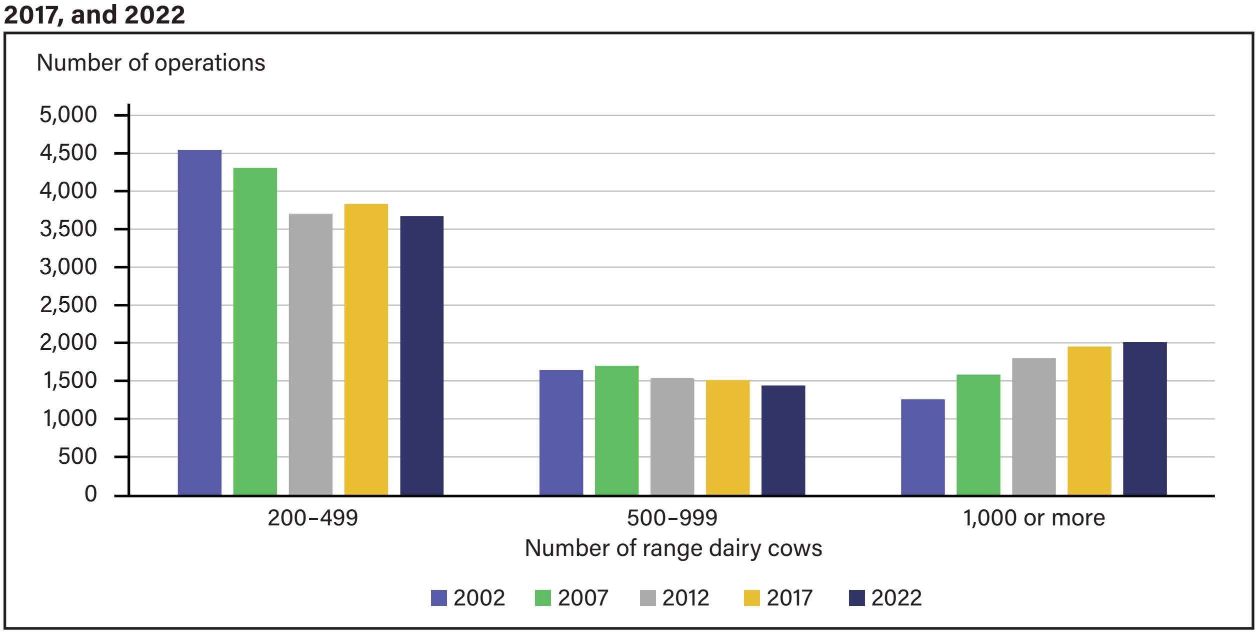
Source: USDA, Economic Research Service using data from USDA, National Agricultural Statistics Service, Milk Production, February issues 2005–18, March 2019, February 2020–24.

Figure 3
Number of U.S. dairy farm operations with fewer than 200 dairy cows by number of dairy cows, 2002, 2007, 2012, 2017, and 2022



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

Figure 4
Number of U.S. dairy farms with 200 dairy cows or more by number of dairy cows, 2002, 2007, 2012, 2017, and 2022

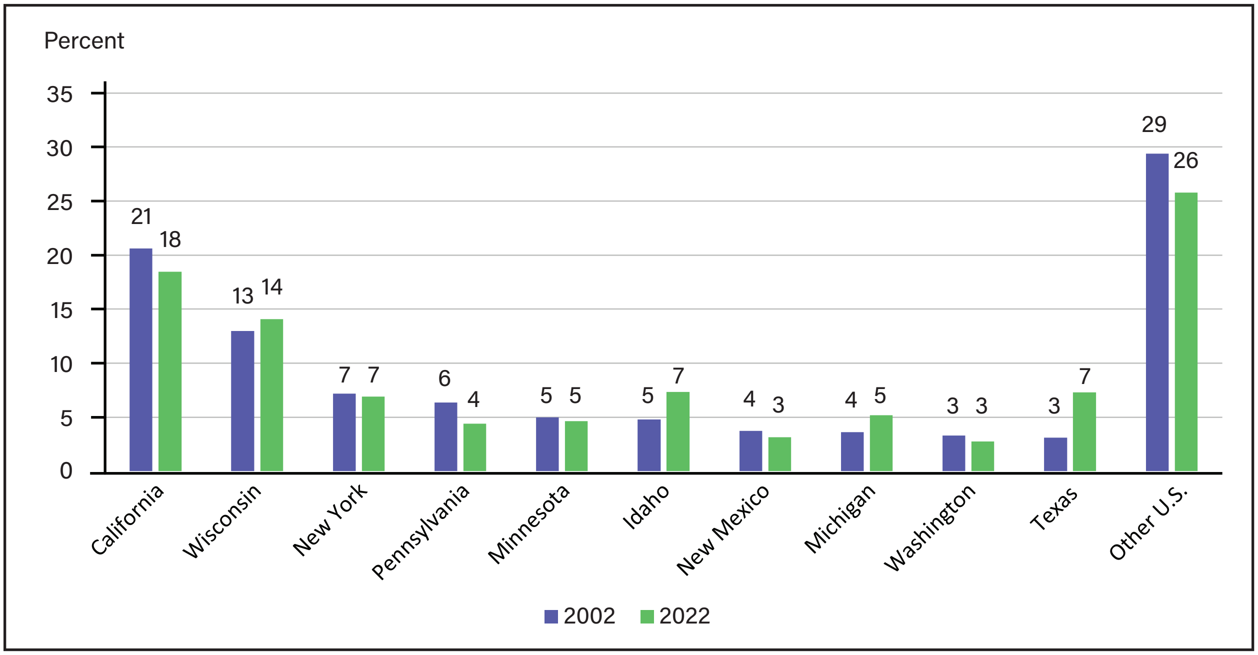


Source: USDA, Economic Research Service using data from USDA, National Agricultural Statistics Service, Census of Agriculture.

Though the highest-producing U.S. dairy States have generally remained among the top producers over the past two decades, there have been notable changes in ranking by size. Figure 5 shows the percentage of milk produced in each of the top 10 dairy-producing States in 2022, which can be contrasted with the percentage of milk produced in each of the same States in 2002. The State with the largest increase in U.S. milk production share over the period was Texas, which increased from 3 percent to 7 percent of production. Idaho increased its share of U.S. milk production by 2 percentage points, from 5 percent to 7 percent. On the other hand, States that were not included in the top 10 milk producing States decreased production share by 3 percentage points, from 29 percent to 26 percent.

Figure 5

Percentage of U.S. milk produced among the top 10 milk-producing States, 2002 and 2022

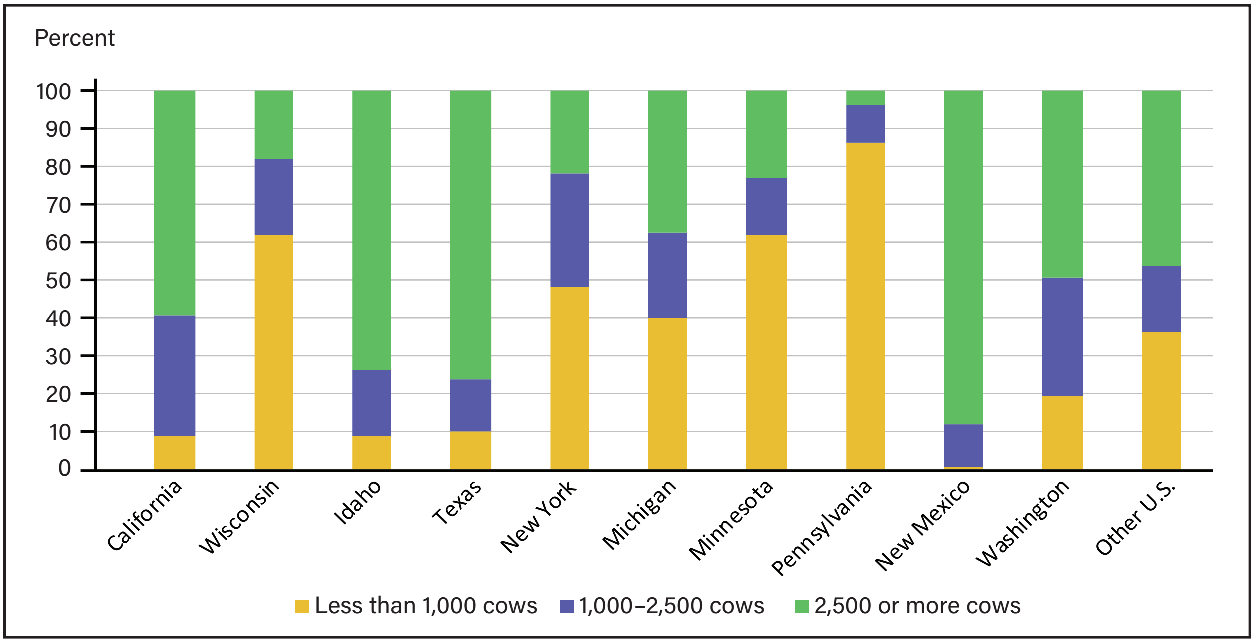


Source: USDA, Economic Research Service using data from USDA, National Agricultural Statistics Service, Milk Production, Disposition, and Income 2002 Summary and Milk Production, Disposition, and Income 2022 Summary.

States differ in their distribution of sales among farm size categories. Figure 6 shows percentages of milk sales in dollars from farms of three different size categories by December 1, 2022, cow inventory: Less than 1,000 cows, 1,000 to 2,499 cows, and 2,500 cows or more. Idaho, Texas, and New Mexico each had more than 70 percent of their milk sales from farms with 2,500 cows or more. On the other hand, Wisconsin, Minnesota, and Pennsylvania each had more than 60 percent of their milk sales from farms with fewer than 1,000 cows.

Figure 6

Percentages of milk sales in dollars from farms by December 31, 2022, dairy cow inventory, by State, top 10 States in milk production, 2022



Source: USDA, Economic Research Service using data from USDA, National Agricultural Statistics Service, Census of Agriculture, 2022.

Analyzing Dairy Farm Structural Change Using ARMS Data

The Agricultural Resource Management Survey (ARMS) data allow for a deeper look at recent changes in the structure of U.S. milk production. Measures of farm size and diversification, operator demographics, and economic indicators for U.S. dairy farms for each of the five ARMS dairy survey years over the past two decades are shown in table 1. The number of observations listed shows the number of survey responses received. The number of farms is determined as the sum of the expansion weights for the surveyed farms included in the ARMS or the number of farms each observation represents. Consistent with figure 1 data for licensed dairy farms, the number of dairy farms represented by ARMS declined over the period. An upward trend in pounds of milk sold per cow is shown, which is consistent with the upward trend shown in figure 2. Survey results show increased operation sizes over the period 2000–21, with the average surveyed farm having 283 cows in 2021, compared with 112 cows in 2000, a 153-percent increase. The midpoint dairy herd size is defined as the herd size where half of the U.S. inventory of dairy cows is on farms with fewer dairy cows (rounding to the nearest 10). Using the ARMS dairy data, the midpoint dairy herd size for 2021 was 1,260 cows. A sharp increase is noted over successive dairy surveys, starting with 180 cows in 2000. In comparison, MacDonald et al. (2020) used USDA, NASS Census of Agriculture data to report that the midpoint dairy herd size in 1987 was 80 cows, which contrasted with 1,300 cows in 2017.

The number of average dairy farm acres operated (which includes the land on which the dairy and all other farm enterprises are located) also consistently trended upward, from 372 acres in 2000 to 483 acres in 2022, a 30-percent increase. Note that the percentage increase in milk cows was higher than the percentage increase in farm acres operated, which is partially explained by progressively lower farm diversification in the production of other crops and livestock commodities. The percentage of a farm's value of production from milk was 83 percent in 2000 and 88 percent in 2021, and the percentage of dairy farms also producing hay and small grain crops that may be used for dairy feed trended downward over the period. Throughout the period, an increasing percentage of milk was produced on certified organic, as opposed to conventional, dairy farms. Dairy farm operator age trended upward throughout the period, consistent with increased farm operator age over time for all farms, as shown by the USDA, NASS Census of Agriculture.

Table 1

Farm size, farm diversification, operator demographics, and economic indicators of U.S. dairy farms (means unless otherwise noted)

Measure	2000	2005	2010	2016	2021
Observations	872	1,814	1,915	1,526	828
Number of farms	71,331	52,237	48,761	36,556	32,123
Pounds of milk sold per cow	16,388	18,749	20,321	21,698	22,653
Number of cows milked	112	155	175	245	283
50 percent of dairy cows were on farms milking fewer than this number of cows (rounded to nearest 10)	180	340	540	1,040	1,260
Acres operated	372	408	431	471	483
Percent of value of production from milk	83	88	86	86	88
Percent of milk produced on organic dairy farms[1]	NA	0.54	2.40	2.77	2.89
Percent of farms producing					
Corn	83	80	78	82	75
Soybeans	22	23	26	29	26
Hay	89	84	81	78	63
Small grain crops	39	31	29	28	23
Operator age, mean	49	51	51	53	54
Percent of operators with college degree	10	16	11	11	15
Debt-asset ratio	0.19	0.15	0.21	0.20	0.17
Gross cash farm income[2]	444,246	717,287	836,700	1,222,468	1,419,056
Total variable expenses[2]	285,827	465,023	592,148	867,376	1,015,446
Total fixed expenses[2]	50,904	60,191	74,463	91,264	97,692
Net cash farm income[2][3]	107,514	192,074	170,090	263,828	305,918
Total operator household income[2][4]	78,606	133,880	112,286	180,308	203,902
Total operator household farm income[2]	51,827	108,154	85,001	143,605	157,389
Total operator household off-farm income[2]	26,780	25,726	27,285	36,703	46,513

NA = not available.

[1] These farms are certified organic dairy farms. In comparison, the number of total organic milk sales (using the 2016 and 2021 USDA, National Agricultural Statistics Service (NASS) Certified Organic Surveys and total milk sales, as reported by USDA, NASS Milk Production, Disposition, and Income, 2016 and 2021 report) suggests that about 1.91 percent and 2.30 percent of total farm milk sales were organic in 2016 and 2021, respectively.

[2] These measures are expressed in constant 2021 dollars using the U.S. Department of Commerce, Bureau of Economic Analysis (BEA) Gross Domestic Product Price Index (BEA Application Programming Interface Series Code A191RG).

[3] Net cash farm income is gross cash farm income less cash expenses, which include variable and fixed expenses. It does not include costs such as economic depreciation, noncash benefits for hired labor, and economic opportunity costs. Net cash farm income may support multiple households. Agricultural Resource Management Survey (ARMS) data show that most dairy farms with 200 or more cows supported multiple households in 2021.

[4] Total operator household income is the sum of operator household farm income and off-farm income. Farms may have multiple operators. The household income measures reported in this table are for the household of the individual who is most responsible for the decisions made on the operation.

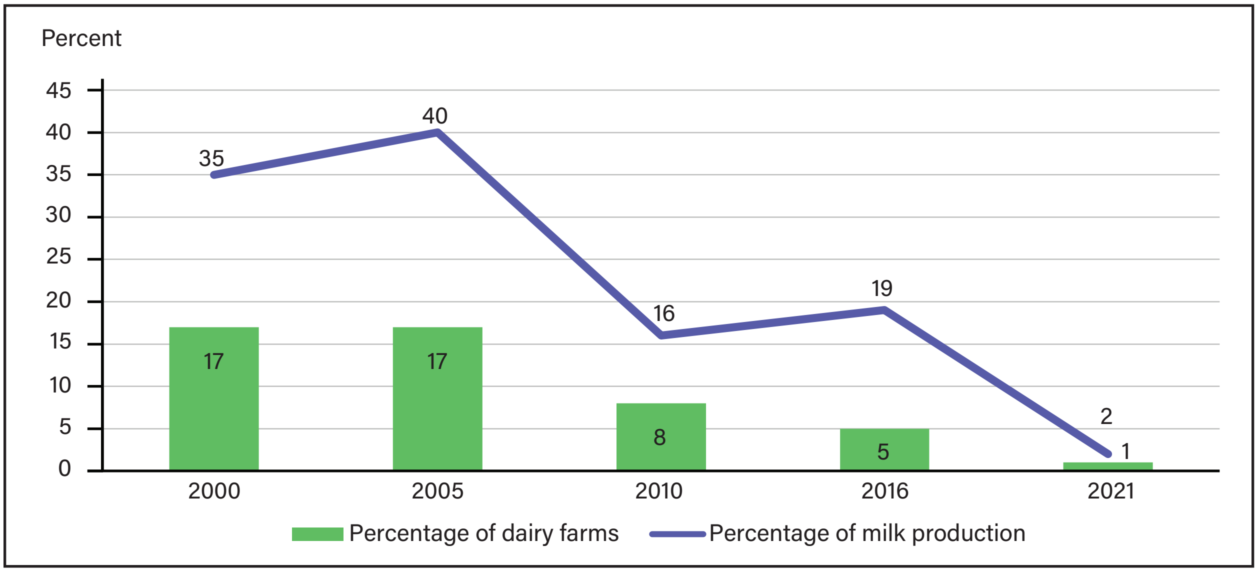
Source: USDA, Economic Research Service (ERS) estimates based on the 2000, 2005, 2010, 2016, and 2021 Agricultural Resource Management Survey dairy version, jointly administered by USDA, ERS and USDA, National Agricultural Statistics Service.

Whole-farm gross cash farm income and all expense categories, adjusted for inflation, trended upward for dairy farms during 2000–21, consistent with the trend toward larger scale operations. Also trending upward over the period were total operator household income, operator household farm income, and total operator household off-farm income.[3] Using the farm household income measures shown in table 1, no obvious trend is shown for the percentage of operator income from off-farm sources, varying from 19 percent in 2005 to 34 percent in 2000.

The use of various technologies, management practices, and production systems can impact cow productivity and resource usage on a dairy farm. Figure 7 shows downward trends in the percentage of U.S. dairy farms and the percentage of U.S. milk sold from dairy farms using recombinant bovine somatotropin (rbST) (or recombinant bovine growth hormone (rbGH)) on their operations. The higher percentage of U.S. milk sold from dairy farms using the technology, relative to the percentage of dairy farms using the technology, indicates that the rbST technology was used primarily by larger farms. USDA, Animal and Plant Health Inspection Service (2022) also shows greater usage of rbST by larger farms and declining usage overall from 1996 to 2014. Declines in rbST use have occurred as dairy companies led the phase-out over marketing concerns and studies such as Stefanides and Tauer (1999) and McBride et al. (2004). These studies showed either no statistically significant impact of rbST on dairy farm profitability or impacts only for large dairy farms (Gillespie et al., 2010).

Figure 7

Percentage of U.S. dairy farms and percentage of U.S. milk sales from dairy farms using recombinant bovine somatotropin (rbST), 2000, 2005, 2010, 2016, and 2021



Source: USDA, Economic Research Service (ERS) estimates based on the 2000, 2005, 2010, 2016, and 2021 Agricultural Resource Management Survey dairy version, jointly administered by USDA, ERS and USDA, National Agricultural Statistics Service.

Results suggest that usage of advanced breeding practices, (including artificial insemination, embryo transplants, and/or sexed semen[4]) has remained relatively steady during 2005–21, at about 80 percent of dairy farms that produced 89 to 96 percent of the U.S. milk sold (figure 8). In comparison, USDA's Animal and

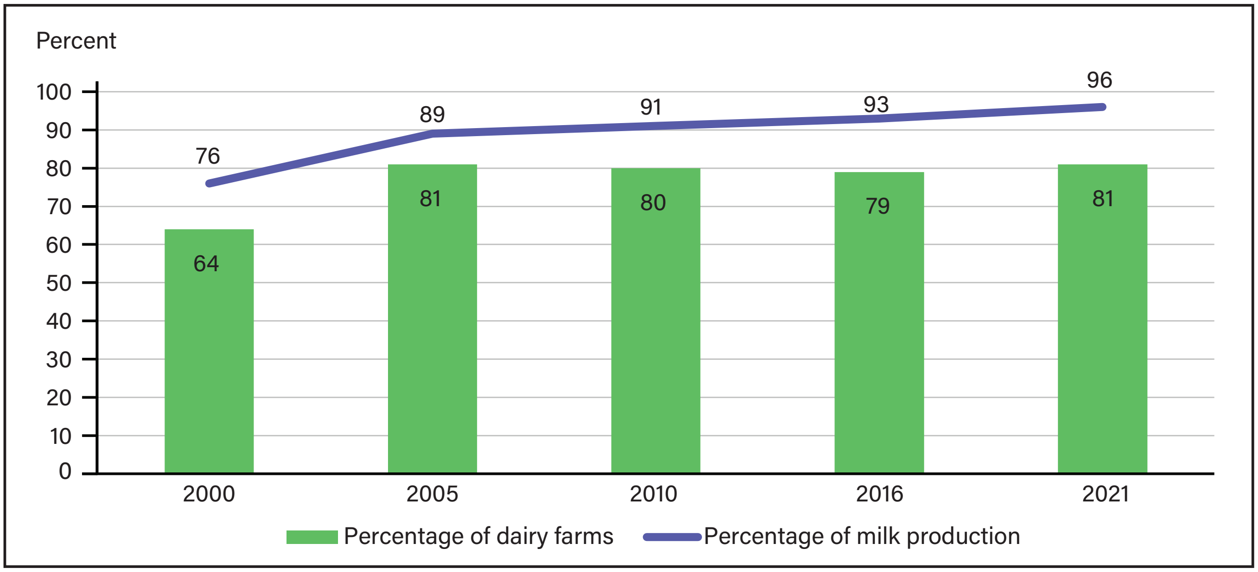
[3] According to the USDA, ERS Farm Household Income and Characteristics Data, the mean nonfarm portion of farm household income for all U.S. farms, not just dairy, increased between 2000 and 2021 from $59,351 to $104,460. Using the Gross Domestic Product Price Index and expressing in 2021 dollars, the calculated change was from $90,472 to $104,460.

[4] The use of artificial insemination, embryo transplants, and/or sexed semen adoption was asked as one question in the 2016 and 2021 ARMS dairy surveys. In previous surveys, artificial insemination was separated from embryo transplants and/or sexed semen.

Plant Health Inspection Service (APHIS) (2022) reported that 89 percent of dairy operations with 30 or more dairy cows used any artificial insemination in 2007 and 2014. Artificial insemination allows for the use of semen from bulls of superior genetics with the added advantage of not having to manage bulls that can be difficult to handle. Embryo transplants (or embryo transfer) allow an embryo of superior genetics to be transplanted to a cow of generally lower genetic quality and be carried from pregnancy to birth. The use of sexed semen allows for changing the percentage of female versus male offspring in breeding programs. Though the ARMS dairy version does not capture specific reasons for use of these technologies, Berry (2020) and Culbertson (2023) discussed reasons for recent increased use of sexed semen for selective breeding of the most productive cows to produce dairy heifers for replacements, and beef semen for other cows to produce higher value calves to enter the slaughter market. Furthermore, genomic selection programs for dairy cattle, discussed by Wiggans and Carrillo (2022), has increased genetic benefits in the United States.

Figure 8

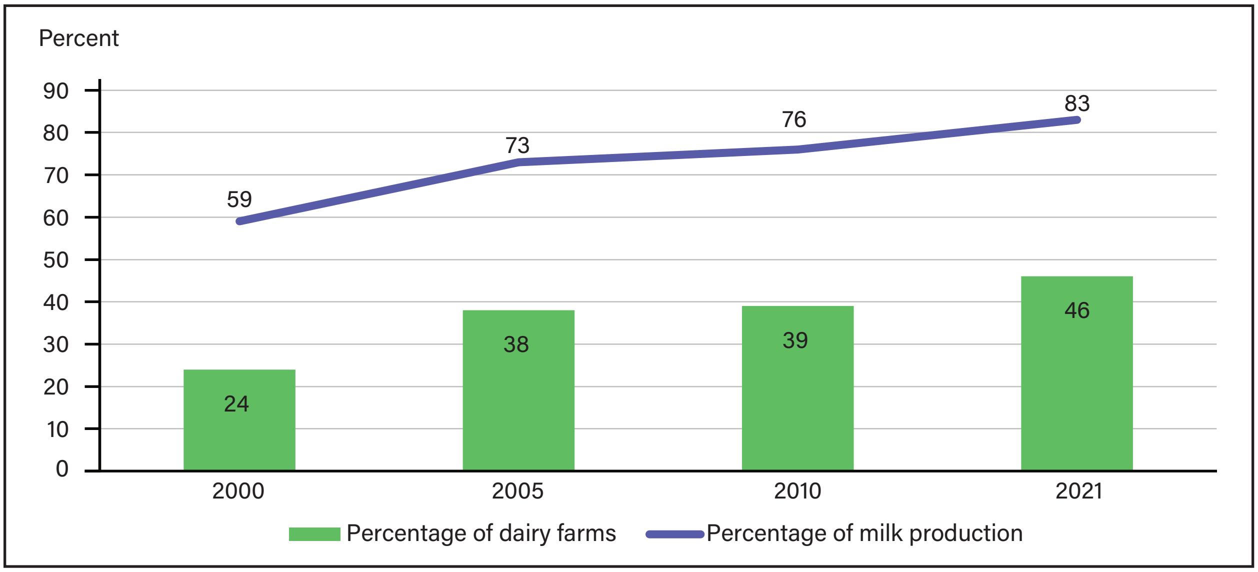
Percentage of U.S. dairy farms and percentage of U.S. milk sales from dairy farms using artificial insemination, embryo transplants, or sexed semen (2000, 2005, 2010, 2016, and 2021)



Source: USDA, Economic Research Service (ERS) estimates based on the 2000, 2005, 2010, 2016, and 2021 Agricultural Resource Management Survey dairy version, jointly administered by USDA, ERS and USDA, National Agricultural Statistics Service.

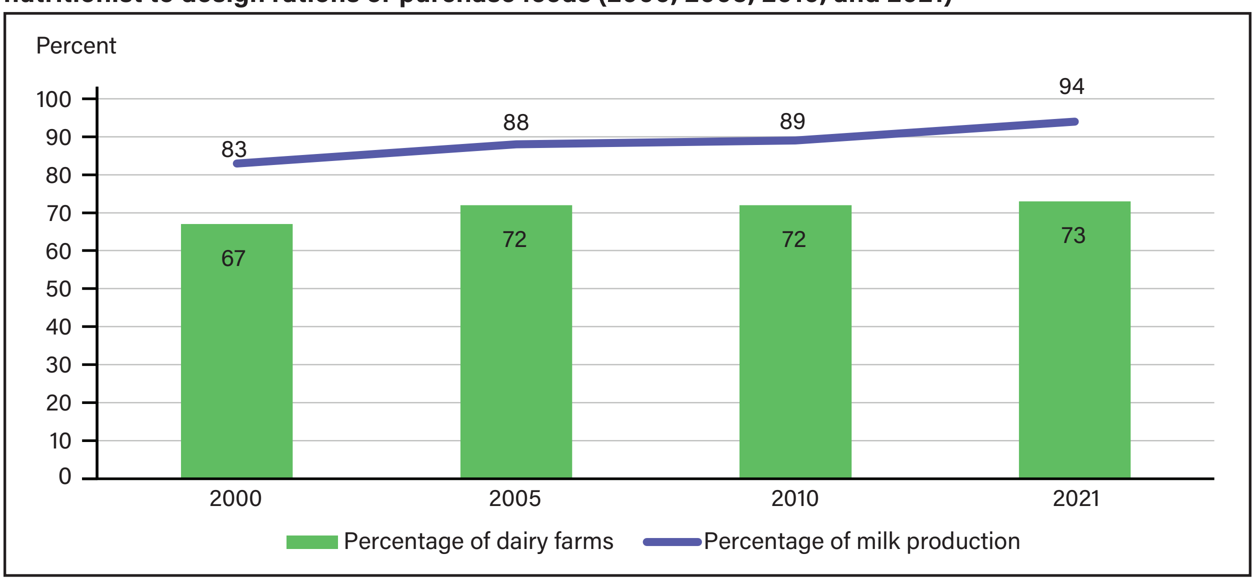
The use of automatic take-offs (which are sensors on milking machines used to determine the end of milk flow and allow the machine to shut off automatically) and a nutritionist to design rations or purchase feeds were queried in all years of the ARMS dairy version except for 2016. Automatic take-offs can reduce the incidence of mastitis and a high somatic cell count. Upward trends occurred in the use of automatic take-offs during 2000–21, from 24 percent of farms using them in 2000 to 46 percent in 2021 and from 59 percent of milk sales from farms using the technology in 2000 to 83 percent in 2021 (figure 9). The use of a nutritionist to design feed rations and purchase feeds remained relatively steady during the same time span, at 67 to 73 percent of farms and 83 to 94 percent of total milk sales from farms using the management practice (figure 10).

Figure 9
Percentage of U.S. dairy farms and percentage of U.S. milk sales from dairy farms using automatic take-offs (2000, 2005, 2010, and 2021)



Source: USDA, Economic Research Service (ERS) estimates based on the 2000, 2005, 2010, and 2021 Agricultural Resource Management Survey dairy version, jointly administered by USDA, ERS and USDA, National Agricultural Statistics Service.

Figure 10
Percentage of U.S. dairy farms and percentage of U.S. milk sales from dairy farms using a nutritionist to design rations or purchase feeds (2000, 2005, 2010, and 2021)

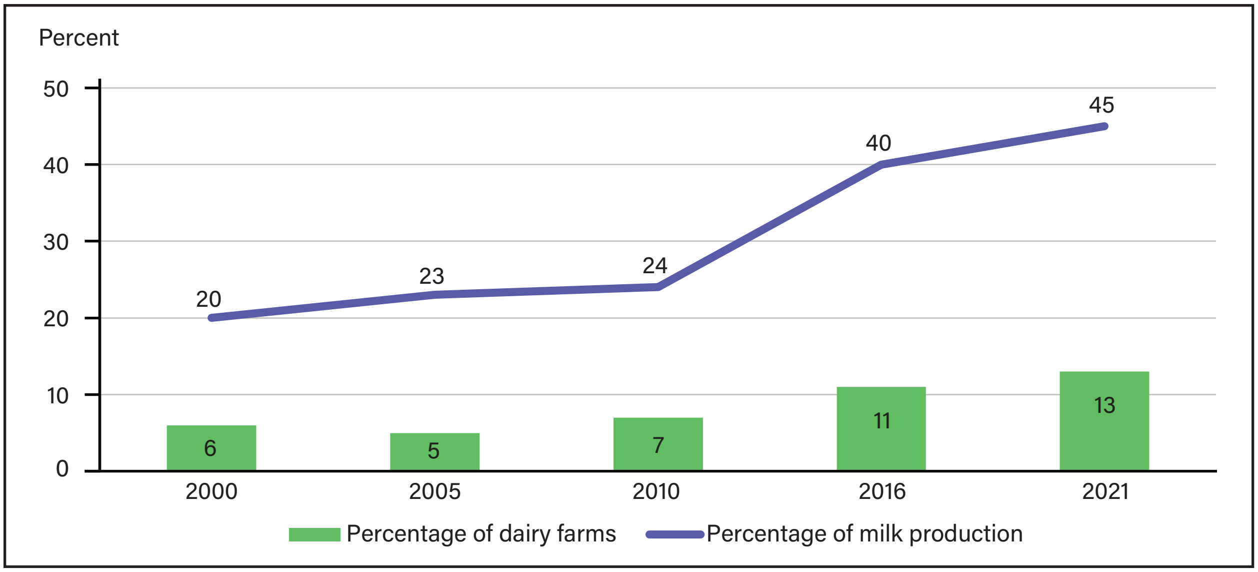


Source: USDA, Economic Research Service (ERS) estimates based on the 2000, 2005, 2010, and 2021 Agricultural Resource Management Survey dairy version, jointly administered by USDA, ERS and USDA, National Agricultural Statistics Service.

An ARMS question about computerized milking systems was, "During (year), were the milking systems computerized to gather data about each milking?" This technology refers to a rather broad set of computerized technologies from which individual cow data are gathered during each milking. An upward trend was shown in the use of computerized milking systems, from 6 percent of farms in 2000 to 13 percent in 2021 (figure 11). The percentage of milk sold by farms using computerized milking systems increased from 20 percent in 2000 to 45 percent in 2021, much higher than the percentage of farms using the technology, indicating the greater use of this technology by larger farms. The definition of a computerized feed delivery system can vary. These systems may be designed to identify a specific cow and feed her according to her needs, and the systems may time the feed allocation to cows. The percentage of farms using computerized feed delivery systems has remained relatively steady over the past two decades, from 8 percent in 2000 to 10 percent in 2021, but the percentage of milk sold from farms using this technology increased from 22 percent in 2000 to 52 percent in 2021 (figure 12). The keeping of individual cow production records has remained relatively steady over the period, ranging from 61 percent of dairy farms in 2005 to 63 percent in 2021 and 82 percent of milk sold from farms using the management practice in 2005 to 90 percent in 2021 (figure 13).

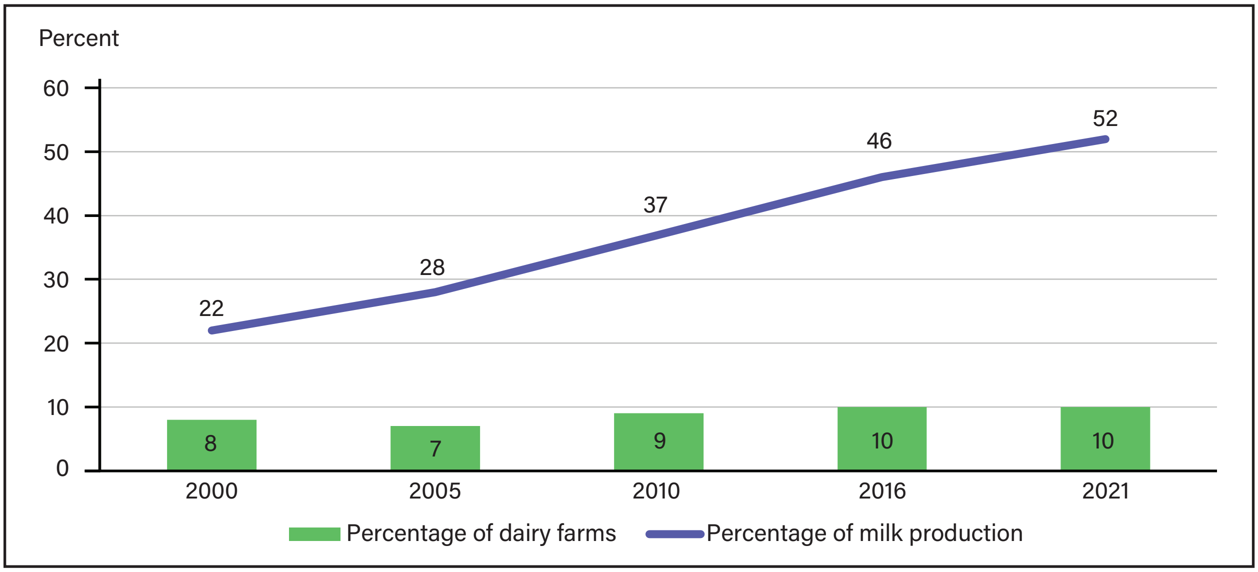
Figure 11

Percentage of U.S. dairy farms and percentage of milk sales from dairy farms using computerized milking systems, 2000, 2005, 2010, 2016, and 2021



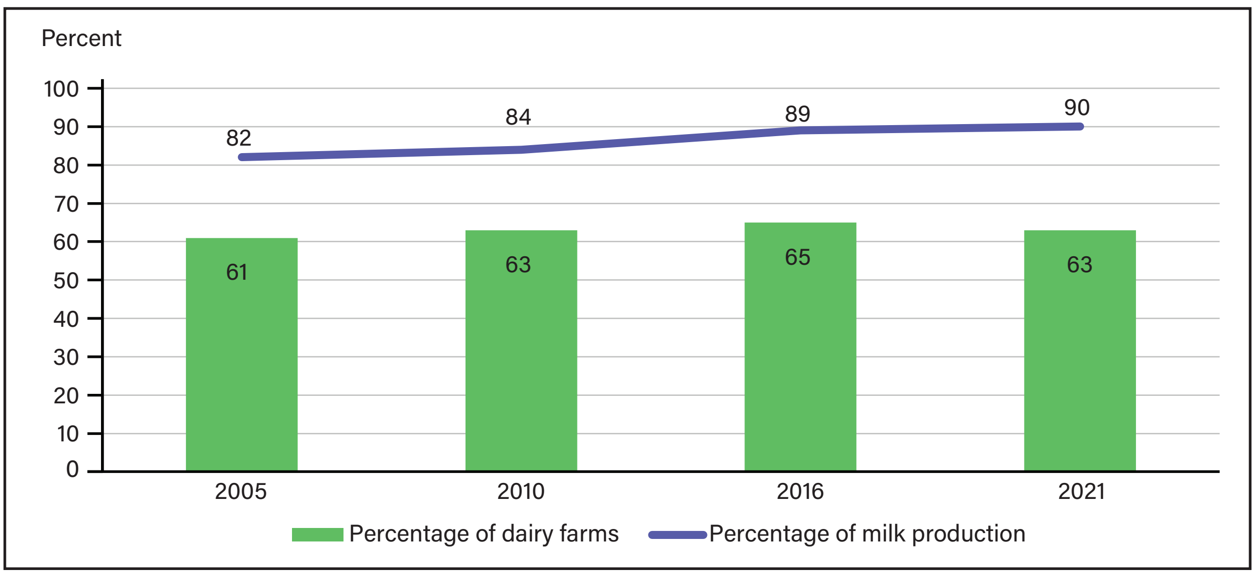
Source: USDA, Economic Research Service (ERS) estimates based on the 2000, 2005, 2010, 2016, and 2021 Agricultural Resource Management Survey dairy version, jointly administered by USDA, ERS and USDA, National Agricultural Statistics Service.

Figure 12
Percentage of U.S. dairy farms and percentage of milk sales from dairy farms using computerized feeding systems, 2000, 2005, 2010, 2016, and 2021



Source: USDA, Economic Research Service (ERS) estimates based on the 2000, 2005, 2010, 2016, and 2021 Agricultural Resource Management Survey dairy version, jointly administered by USDA, ERS and USDA, National Agricultural Statistics Service.

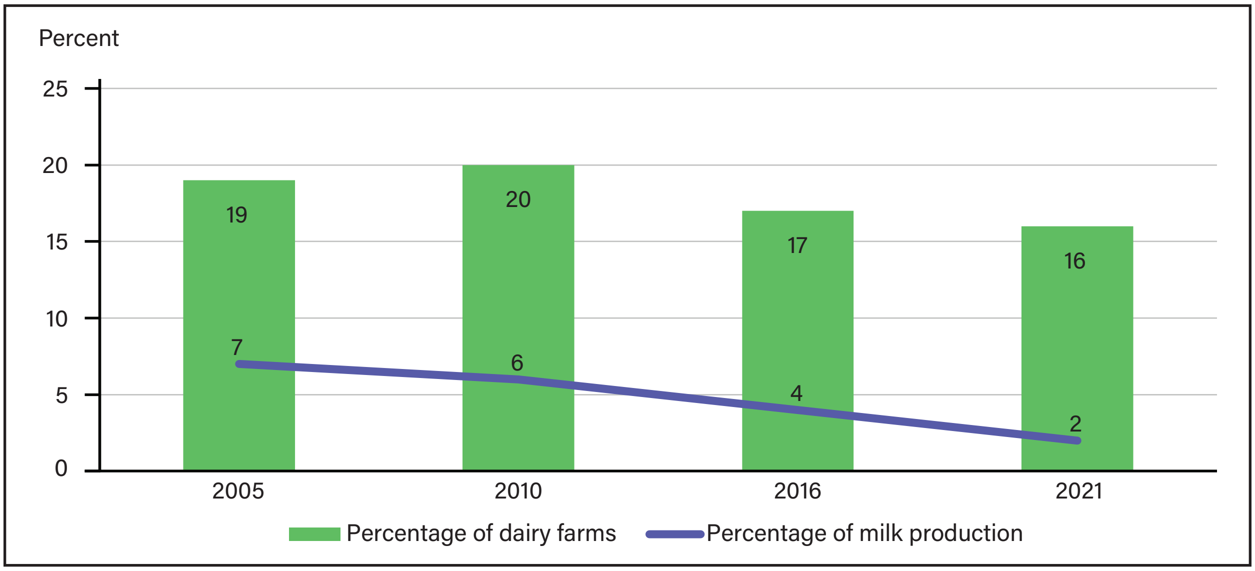
Figure 13
Percentage of U.S. dairy farms and percentage of milk sales from dairy farms keeping individual cow production records, 2005, 2010, 2016, and 2021



Source: USDA, Economic Research Service (ERS) estimates based on the 2005, 2010, 2016, and 2021 Agricultural Resource Management Survey dairy version, jointly administered by USDA, ERS and USDA, National Agricultural Statistics Service.

Pasture-based production systems involve allowing cows to graze for at least a portion of their feed. For purposes of this study, a pasture-based system is defined as one where cows receive at least 50 percent of their forage needs from pasture during the grazing season, though this definition can vary among studies. Some pasture-based operations may receive a premium price for milk to be labeled as such, and some can transition to certified organic with additional management changes. Pasture-based operations generally produce lower volumes of milk per cow. Pasture-based operations have shown a downward trend in use during 2005–21, with the percentage of farms using the system decreasing from 19 percent to 16 percent and the percentage of milk sold from farms using the system decreasing from 7 percent to 2 percent (figure 14). During this time span, the lower percentage of milk sold from farms using pasture-based systems, relative to the percentage of farms using the system, indicated its usage was primarily on smaller dairy farms. About 55 percent of the pasture-based operations were certified organic in 2021.

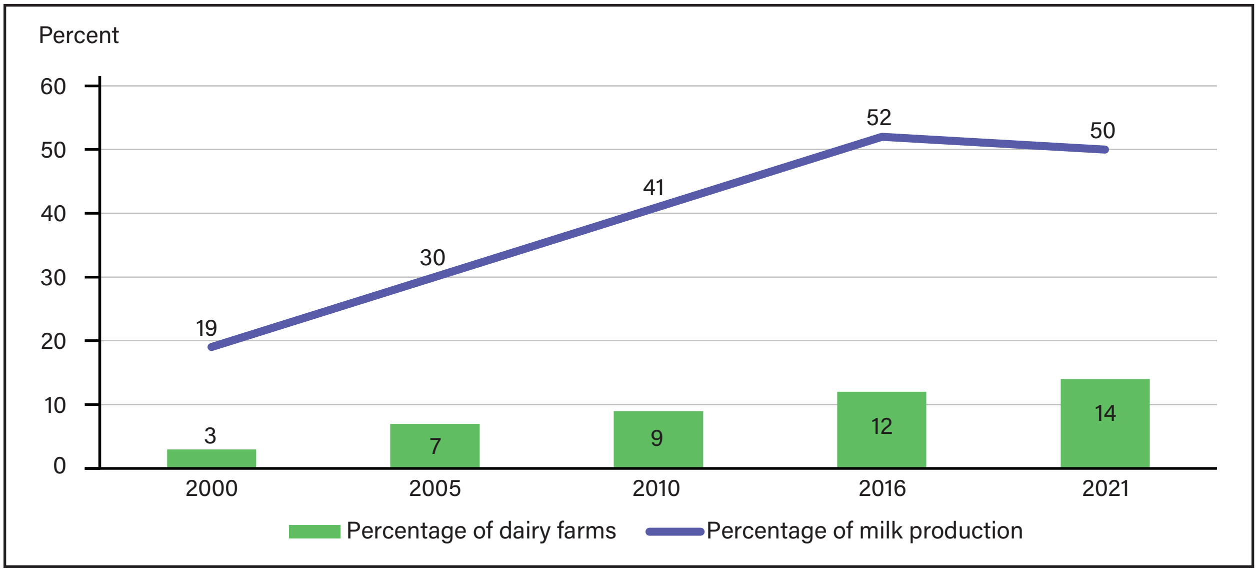
Figure 14
Percentage of U.S. dairy farms and percentage of milk sales from dairy farms using pasture-based production systems, 2005, 2010, 2016, and 2021



Source: USDA, Economic Research Service (ERS) estimates based on the 2005, 2010, 2016, and 2021 Agricultural Resource Management Survey dairy version, jointly administered by USDA, ERS and USDA, National Agricultural Statistics Service.

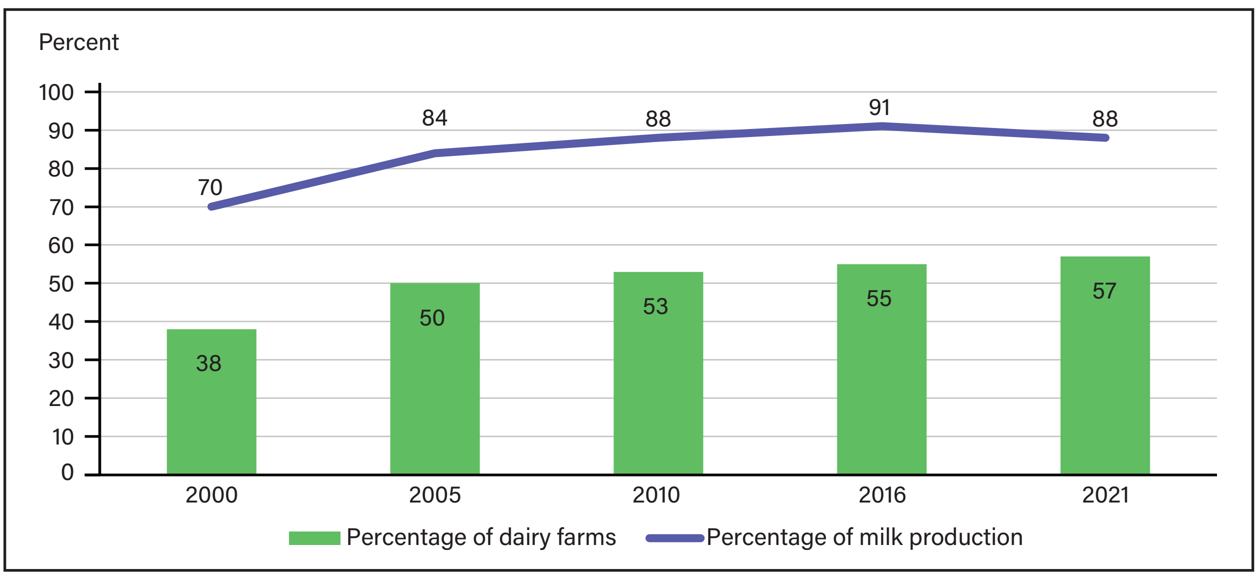
The primary advantage to milking cows three or more times daily, versus the more common milking twice daily, is the increase in milk production per cow, though the increase is generally not proportionate to the number of times the cow is milked. Upward trends are noted for the percentage of dairy farms milking cows three or more times daily, from 3 percent in 2000 to 14 percent in 2021. The trends also show a relatively higher percentage of milk sold from dairy farms milking three or more times daily, from 19 percent to 52 percent (figure 15). The relatively large differences in the percentages of these two measures are due to the higher usage of milking three or more times daily among larger farms. In parlor systems, cows generally enter stalls for milking. This practice is contrasted with stanchion or tie stall barns, which usually use around-the-barn pipeline or bucket-milker systems. An upward trend in parlor system use is shown in figure 16, with the percentage of farms using a dairy parlor increasing from 38 percent in 2000 to 57 percent in 2021 and the percentage of milk sold from farms using dairy parlors increasing from 70 percent in 2000 to 88 percent in 2021.

Figure 15
Percentage of U.S. dairy farms and percentage of milk sales from dairy farms milking cows three or more times daily, 2000, 2005, 2010, 2016, and 2021



Source: USDA, Economic Research Service (ERS) estimates based on the 2000, 2005, 2010, 2016, and 2021 Agricultural Resource Management Survey dairy version, jointly administered by USDA, ERS and USDA, National Agricultural Statistics Service.

Figure 16
Percentage of U.S. dairy farms and percentage of milk sales from dairy farms using a milking parlor, 2000, 2005, 2010, 2016, and 2021



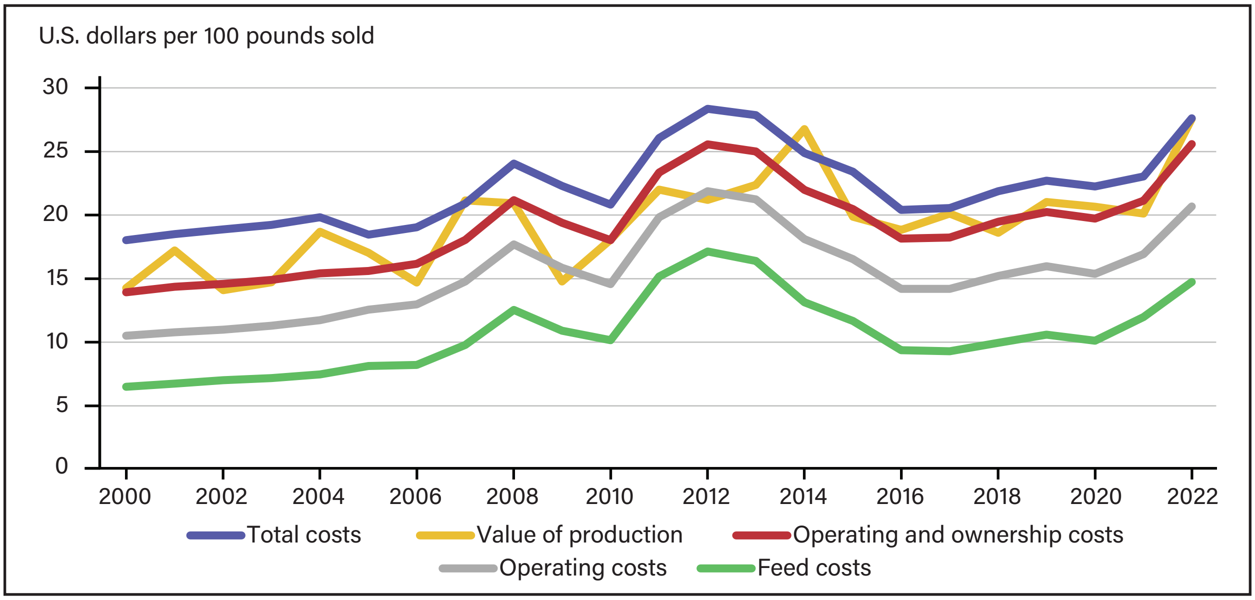
Source: USDA, Economic Research Service (ERS) estimates based on the 2000, 2005, 2010, 2016, and 2021 Agricultural Resource Management Survey dairy version, jointly administered by USDA, ERS and USDA, National Agricultural Statistics Service.

Milk Costs and Returns During 2000–22

Costs and returns associated with producing 100 pounds of milk are estimated annually by USDA, ERS and published as part of the Commodity Costs and Returns (CAR) data series. The CAR data associated with milk production from 2000 to 2022 are examined in this 2024 ERS report. The value of production includes milk sold, cattle sales, and other income, including the fertilizer value of manure and returns from renting space to other dairy operations. Operating costs include: the costs of purchased feed; homegrown harvested feed, which is valued at the market price of the feed as fed; grazed feed, which is valued at the rental rate of pasture; veterinary and medicine; bedding and litter; marketing charges; fuel, lube, and electricity; repairs; hired labor; interest on operating capital; and the cost of organic certification for certified organic dairy farms. Ownership costs include the costs of capital recovery of machinery and equipment (which approximate depreciation and interest as an opportunity cost), taxes, and insurance. Opportunity and overhead costs include the opportunity cost of unpaid labor, the opportunity cost of land, and general farm overhead expenses. More specific definitions for each of these cost categories can be found on the Documentation web page for USDA, ERS Commodity CAR data.

Costs and returns associated with producing 100 pounds of milk in the United States during 2000–22 are shown in figure 17. The amber-colored line shows the value of production associated with producing milk.[5] Feed costs were covered by the average dairy farm in all years. Total operating costs (which include feed) were covered by the average dairy farm in all but 2 years, 2009 and 2012. Total operating and ownership costs were covered by the average dairy farm in about half of the years. Finally, total economic costs were covered by the average dairy farm in only 2 years, 2007 and 2014, from 2000 to 2022.

Figure 17
Costs and returns associated with U.S. milk production, 2000–22



Note: Vertical lines indicate the Agricultural Resource Management Survey (ARMS) dairy-version years.
Source: USDA, Economic Research Service, Commodity Costs and Returns data, 2023.

Farms that are not covering total costs may continue to operate, particularly in the short run. This may result from their not covering opportunity costs (such as for unpaid labor, owned land, or interest on buildings and machinery, which is part of the capital recovery cost). While these are economic costs associated with producing milk, they are not out-of-pocket cash costs. Also, costs and returns presented in the USDA, ERS Commodity CAR data do not include Government payments or costs associated with Government programs, though Government programs can impact dairy farm CAR. Dairy Margin Coverage (DMC), as discussed by the USDA, Farm Service Agency (FSA) (2022), is a voluntary program that triggers a payment when the average income (less feed cost) falls below a level selected by the participant. According to USDA, FSA (2024),

[5] Note that dairy producers are paid for the components of milk sold: fat, protein, and other solids. From 2000 to 2022, USDA, ERS Dairy Data showed that the percentage of milk fat in milk produced on U.S. dairy farms increased from 3.68 percent to 4.08 percent.

19,133 dairy operations were enrolled in DMC in 2021, with estimated payments of almost $1.19 billion. Considering there were 29,842 licensed dairy herds in the United States in 2021, the enrollment rate was approximately 64 percent. With 226.3 billion pounds of milk produced in 2021, the average payment per 100 pounds of milk produced was approximately $0.52.[6]

Estimates from the ARMS dairy version indicated that total Government payments to dairy producers were $0.75 per 100 pounds of milk sold in 2021, though it was unclear whether the payments over and above the DMC were for the dairy or another farm enterprise, such as corn or soybeans. Furthermore, ARMS does not provide a basis for estimating costs associated with participation in specific programs other than DMC. Other programs in which dairy producers may have participated include (but are not limited to): Dairy Revenue Protection (Dairy-RP), which is designed to insure dairy producers against unexpectedly low revenue relative to guaranteed coverage; Livestock Gross Margin Insurance Dairy Cattle (LGM-Dairy), which provides protection when milk prices drop or feed prices rise; conservation programs such as the Environmental Quality Incentives Program (EQIP) that are designed to promote conservation practice use; and supplemental and ad hoc disaster assistance programs. The reader who is interested in more information on some of the programs used by dairy producers is directed to USDA, FSA (2022) for the DMC; USDA, Risk Management Agency (RMA, 2019) for Dairy-RP; USDA, RMA (2022) for LGM-Dairy, and USDA, Natural Resources Conservation Service (NRCS, 2023) for conservation programs. For information on the USDA Federal Milk Marketing Order (FMMO) program (which sets the minimum prices that dairy producers receive for milk in some U.S. regions), go to the USDA, AMS FMMO web page.

Comparing Dairy Farms by Size

U.S. dairy farms vary in size, from very small (only a few cows) to very large (several thousand cows or more). Different-sized dairy farms can vary widely in farm structure; adoption of technologies, management practices, and production systems; and costs and returns by operation size. In this section, 2021 ARMS dairy data are used to compare dairy farms by these attributes for 7 size categories: less than 50 cows, 50–99 cows, 100–199 cows, 200–499 cows, 500–999 cows, 1,000–1,999 cows, and 2,000 cows or more.

Dairy farm structure and farm-operator-demographic measures by farm size are shown in table 2. The larger farm size categories include the smallest percentage of dairy farms but the largest percentage of total milk sales. Superscripts in the table indicate the measure differs significantly (at the 90-percent confidence level) from other specified measures in the same row. For example, the entry of 33 cows with superscript "bcdefg" in the "Number of cows" row and "Fewer than 50 cows" column is statistically different from the means in column b (71 for the 50–99 cows category), column c (136 for the 100–199 cows category), and columns d, e, f, and g, etc. As expected, as the number of cows increased, the number of total acres operated on the farm increased. The smallest farms (less than 50 cows) averaged 172 acres, and the largest farms (at least 2,000 cows) averaged 1,909 acres. Annual milk production per cow generally increased with size, with the smallest farms (less than 50 cows) averaging 15,751 pounds per cow per year and farms in the 1,000–1,999 cow category averaging 24,895 pounds per cow per year.

Larger dairies generally received a higher percentage of their total value of farm production from the dairy enterprise. Farms with at least 500 cows received, on average, 90 percent or more of their total farm value of production from the dairy enterprise, while farm size categories with fewer than 500 cows averaged at most 82 percent of their total farm value of production from milk. Differences in the percentage of farms

[6] In contrast, the ARMS, dairy version, 2021 results indicated DMC payments of $0.42 per 100 pounds of milk sold.

producing specific crops by size category were found, with the most notable difference being the lower percentage of larger dairies producing hay. Lower hay production among larger dairy farms was consistent with lower homegrown harvested feed costs per 100 pounds of milk sold among larger dairy farms, as shown by the USDA, ERS Milk Cost of Production Estimates data. Larger dairy farms tended to carry greater debt relative to assets, with debt-to-asset ratios ranging from 0.09 for farms with less than 50 cows to 0.26 for farms with 1,000–1,999 cows. Furthermore, larger farms, on average, received a higher percentage of total operator household income from the farm, ranging from 43 percent for farms with less than 50 cows to 97 percent for farms with more than 2,000 cows. As expected, net cash farm income increased with farm size. Government payments (as a percentage of gross cash farm income) generally decreased with farm size, particularly for farms with 500 cows or more.

Table 2

U.S. dairy farm structure and farm operator demographics, by size, 2021

	<50 cows (a)	50–99 cows (b)	100–199 cows (c)	200–499 cows (d)	500–999 cows (e)	1,000–1,999 cows (f)	≥2,000 cows (g)
Percent of farms	28	33	16	11	5	4	3
Percent of milk sold	2	6	7	13	12	20	39
Number of cows	33[bcdefg]	71[acdefg]	136[abdefg]	304[abcefg]	680[abcdfg]	1,411[abcdeg]	4,011[abcdef]
Acres operated	172[bcdefg]	310[acdefg]	476[abdefg]	813[abcefg]	1,210[abcdg]	1,424[abcd]	1,909[abcde]
Milk produced per cow (pounds)	15,751[cdefg]	17,632[cdefg]	19,991[abdefg]	23,479[abc]	24,596[abc]	24,895[abc]	22,978[abc]
Percent of value of production from milk	78[efg]	80[efg]	82[efg]	82[efg]	90[abcd]	92[abcd]	92[abcd]
Percent of farms producing							
Corn	59[b]	85[ag]	78	83	77	70	71[b]
Soybeans	15[d]	30	26[d]	46[acf]	29	15[d]	D
Hay	65[fg]	74[defg]	58[fg]	59[bfg]	49[bg]	36[abcd]	28[abcde]
Small grains	21	24	24	28	29	16	13
Debt-to-asset ratio	0.09[cdefg]	0.12[defg]	0.16[af]	0.17[abf]	0.22[ab]	0.26[abcd]	0.19[ab]
Percent operator household income from farm[1]	43[cdfg]	61[cdfg]	73[abdfg]	81[abcfg]	69[fg]	96[abcde]	97[abcde]
Net cash farm income[2]	43,630[bcdefg]	114,086[acdefg]	194,809[abdefg]	427,085[abcfg]	634,074[abcfg]	1,415,193[abcdeg]	3,424,991[abcdef]
Percent of gross cash farm income from Government payments	6[fg]	7[efg]	8[defg]	6[cefg]	3[bcdg]	3[abcdg]	1[abcdef]
Operator age (years)	56	52[df]	54[d]	57[bc]	55	57[b]	55
Percent of operators with a 4-year college degree	15	13	15	17	23	29	20

D = insufficient data for disclosure.

Note: A lettered superscript denotes that the item mean reported in a column is significantly statistically different from the item mean reported in the column identified by the superscript letter. Tests are expressed at a 90-percent confidence level. Tests were conducted using a delete-a-group jackknife variance estimator, with 30 replicates provided by the USDA, National Agricultural Statistics Service (NASS) for the Agricultural Resource Management Survey (ARMS) dairy version data, as discussed in Dubman (2000).

[1] Farms may have multiple operators. "Percent operator household income from farm" refers to the household of the individual who is most responsible for the decisions on the operation.

[2] Net cash farm income is gross cash income less cash expenses, which include both variable and fixed expenses. It does not include costs such as economic depreciation, noncash benefits for hired labor, and economic opportunity costs. Net cash farm income may support multiple households. ARMS data show that most dairy farms with 200 or more cows supported multiple households in 2021.

Source: USDA, Economic Research Service (ERS) estimates based on the 2021 ARMS dairy version, jointly administered by USDA, ERS and USDA, National Agricultural Statistics Service.

The adoption rates of selected technologies, management practices, and production systems by dairy farm size are shown in table 3. Farms were aggregated into three size categories: less than 150 cows, 150–499 cows, and at least 500 cows—so that adoption or nonadoption could be represented in a manner that did not result in disclosure concerns. Larger dairy operations were generally greater adopters of the most advanced technologies, management practices, and production systems—with adoption increasing with size for artificial insemination, embryo transplants, or sexed semen; computerized feed delivery systems; keeping individual cow production records; milking units with automatic take-offs; using a nutritionist to design mixes or purchase feed; and computerized milking systems. Larger operations were also more likely to use a dairy parlor and milk cows three or more times per day. These results are consistent with Khanal et al. (2010), who found that larger farms were greater adopters of the most advanced technologies, management practices, and production systems (based on ARMS dairy data for 2000 and 2005). Smaller operations were more likely to be pasture based, with pasture-based operations comprising 21 percent of operations with less than 150 cows but only 3 percent of those with 150 or more cows. One reason why pasture-based systems are less attractive for larger operations is the high effort and cost associated with gathering large herds over extensive acreage for milking. Twenty-one percent of operations with less than 150 cows were certified organic, compared with 6 percent with 150–499 cows and 3 percent with 500 cows or more.

Table 3

Percentage of U.S. dairy farms that adopted selected technologies, management practices, and production systems by farm size, 2021

Technologies, management practices, and production systems	<150 cows (a)	150–499 cows (b)	≥500 cows (c)
Artificial insemination, embryo transplants, or sexed semen	77[c]	85[c]	96[ab]
Computerized feed delivery system	2[bc]	13[ac]	55[ab]
Individual cow production records	54[bc]	82[ac]	94[ab]
Milking units with automatic take-offs	31[bc]	86[a]	89[a]
Nutritionist to design mixes or purchase feed	66[bc]	90[a]	93[a]
Parlor	45[bc]	85[a]	93[a]
Milk three or more times per day	3[bc]	30[ac]	63[ab]
Computerized milking system	4[bc]	29[ac]	50[ab]
Pasture-based	21[bc]	3[a]	3[a]
Certified organic	21[bc]	6[a]	3[a]

Note: The lettered superscripts throughout the table denote statistically significant differences. A lettered superscript denotes that the item mean reported in a column is statistically significantly different from the item mean reported in the column identified by the superscript letter. Tests are expressed at a 90-percent confidence level. Tests were conducted using a delete-a-group jackknife variance estimator with 30 replicates provided by the USDA, National Agricultural Statistics Service (NASS) for the Agricultural Resource Management Survey (ARMS) data, as discussed in Dubman (2000).

Source: USDA, Economic Research Service (ERS) estimates based on the 2021 ARMS dairy version, jointly administered by USDA, ERS and USDA, NASS.

Costs and Returns of Different Sized Dairy Farms

Costs and returns for 2021 by size category are shown in table 4. Some significant differences are noted in the gross value of production by size category, but a clear pattern of differences for this measure by size is not apparent. Price differences can arise due to factors such as production region,[7] conventional/organic status, or other premiums or discounts. There were minor differences in total feed costs by farm size, but sources of feed costs differed. Larger operations purchased greater portions of their feed and thus had higher purchased feed costs per 100 pounds of milk sold. Farms with fewer than 50 cows spent, on average, $5.23 per 100 pounds of milk sold for purchased feed, while farms with at least 2,000 cows spent $9.35. On the other hand, larger operations had lower homegrown feed costs per 100 pounds of milk sold. Farms with less than 50 cows incurred costs of $7.38 per 100 pounds of milk sold for homegrown feed, while farms with at least 2,000 cows incurred costs of $2.40. Grazed feed costs per 100 pounds of milk sold decreased with farm size, with smaller operations depending more heavily on grazing, on average. Paid labor expense per 100 pounds of milk sold increased with farm size. Larger operations depended more heavily on paid labor and less on unpaid (mostly family) labor. Most families on larger farms are not large enough to depend only on unpaid family labor. Summing paid labor and unpaid labor expenses, the range in total labor cost is $2.09 per 100 pounds sold for the 2,000 or more cow category to $15.02 for the less than 50 cow category. The difference is attributed to the adoption of labor-saving technologies, management practices, and production systems—as well as greater efficiencies associated with milking larger numbers of cows. Average total operating costs ranged from $16.16 per 100 pounds of milk sold for farms with at least 2,000 cows to $18.44 for farms with 50–99 cows.

Costs associated with ownership of machinery and buildings (including capital recovery costs, taxes, and insurance) decreased on a per-100-pounds of milk sold basis as farm size increased, ranging from $2.50 for farms with at least 2,000 cows to $9.33 for farms with fewer than 50 cows. This reduction is primarily because building and equipment costs can be spread over more cows as operation size increases, and larger operations tend to have higher average milk production per cow. Likewise, opportunity and overhead costs per unit of milk sold declined with farm size, in part because of the lower dependence on unpaid labor as the primary labor source as farm size increased. Total opportunity and overhead costs ranged from $0.47 per 100 pounds of milk sold for farms with at least 2,000 cows to $15.76 for farms with fewer than 50 cows.

[7] A majority of milk from dairy farmers in the United States is marketed through Federal Milk Marketing Orders (FMMOs). Some of the regional differences observed in table 4 are due to minimum prices regulated by FMMOs. Milk handlers pay minimum prices for milk from dairy farmers based on the end uses of the milk. The minimum prices differ geographically for milk that is processed into fluid milk, and the shares of milk in each of the end-use classes also vary geographically, contributing to regional price variation.

Table 4
U.S. dairy farm costs and returns per 100 pounds of milk sold, by size, 2021

	<50 cows (a)	50–99 cows (b)	100–199 cows (c)	200–499 cows (d)	500–999 cows (e)	1,000–1,999 cows (f)	≥2,000 cows (g)
Value of production							
Milk production	20.38[cdfg]	19.92[fg]	18.91[a]	18.27[a]	19.16[g]	18.55[ab]	17.77[abe]
Animal sales and other income	2.38[deg]	2.05[cdeg]	1.70[bd]	1.49[abc]	1.63[ab]	1.66	1.49[ab]
Gross value of production	22.76[cdefg]	21.98[cdfg]	20.61[abg]	19.76[ab]	20.79[ag]	20.21[ab]	19.25[abce]
Operating costs							
Purchased feed	5.23[efg]	5.70[efg]	5.98[efg]	6.16[efg]	7.77[abcdg]	8.39[abcd]	9.35[abcde]
Homegrown feed	7.38[efg]	8.15[cdefg]	5.90[bfg]	5.61[bfg]	4.28[abg]	3.13[abcd]	2.40[abcde]
Grazed feed	0.29[cdefg]	0.12[defg]	0.08[adfg]	0.02[abcg]	0.03[abg]	0.01[abc]	0.00[abcde]
Total feed cost	12.90	13.97[f]	11.96	11.79	12.08	11.53[b]	11.74
Paid labor	0.54[cdefg]	0.69[cdefg]	1.24[abdefg]	2.18[abc]	2.31[abc]	2.21[abc]	2.01[abc]
Other operating inputs	4.18	3.78[g]	3.75[g]	3.61[g]	3.36[g]	3.00	2.41[bcde]
Total operating costs	17.63	18.44	16.94	17.58	17.75	16.75	16.16
Ownership costs	9.33[efg]	8.05[efg]	6.62[efg]	6.55[g]	3.91[abcg]	3.57[abc]	2.50[abcde]
Opportunity and overhead costs							
Cost of unpaid labor	14.48[bcdefg]	7.16[acdefg]	3.60[abdefg]	1.24[abcefg]	0.52[abcdfg]	0.24[abcdeg]	0.08[abcdef]
Cost of land and overhead	1.27[c defg]	0.93[efg]	0.77[adefg]	0.57[acg]	0.52[abc]	0.45[abc]	0.40[abcd]
Total opportunity and overhead costs	15.76[bcdefg]	8.08[acdefg]	4.37[abdefg]	1.81[abcefg]	1.05[abcdfg]	0.69[abcdeg]	0.47[abcdef]
Total cost	42.71[bcdefg]	34.58[acdefg]	27.93[abefg]	25.94[abfg]	22.70[abcg]	21.01[abcd]	19.14[abcde]
Net return measures							
Net return over feed cost	9.86[g]	8.01	8.66	7.97	8.71	8.68	7.51[a]
Net return over operating cost	5.13[d]	3.54	3.67	2.18[a]	3.04	3.46	3.09
Net return over operating and ownership cost	-4.19	-4.52[efg]	-2.95[g]	-4.37[efg]	-0.87[bd]	-0.11[bd]	0.59[bcd]
Net return over total cost	-19.95[bcdefg]	-12.60[acdefg]	-7.32[abefg]	-6.18[abefg]	-1.91[abcd]	-0.80[abcd]	0.12[abcd]

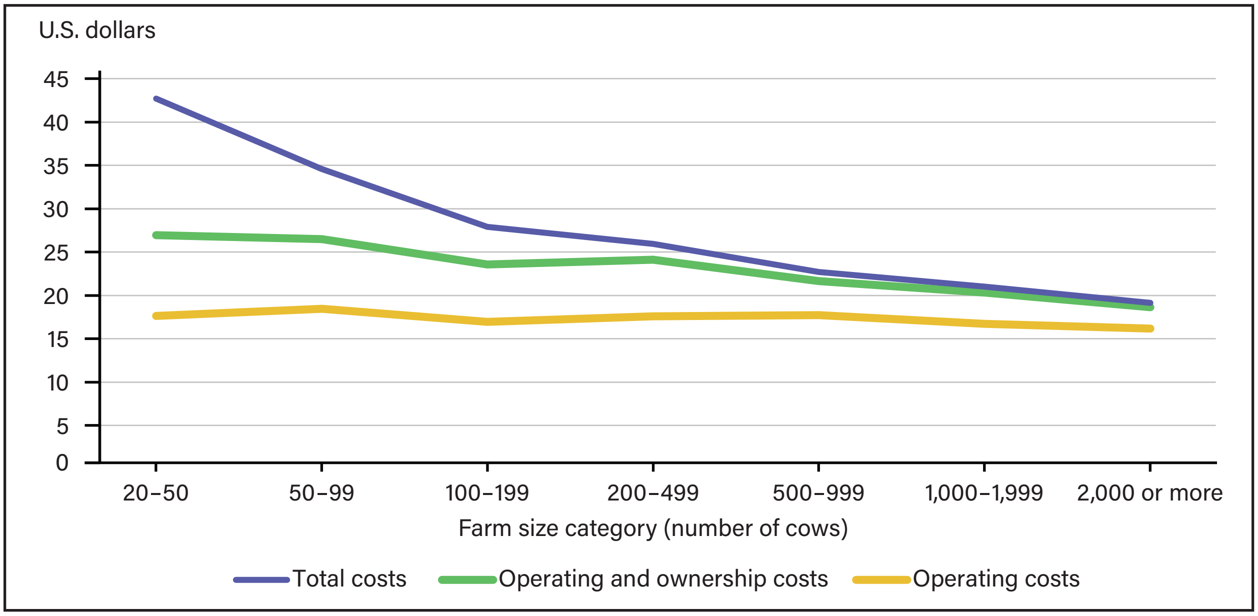
Note: Lettered superscripts denote significant statistical differences. A lettered superscript denotes that the item mean reported in a column is significantly statistically different from the item mean reported in the column identified by the superscript letter. Tests are expressed at a 90-percent confidence level. Tests were conducted using a delete-a-group jackknife variance estimator, with 30 replicates provided by the USDA Agricultural Resource Management Survey (ARMS) data, as discussed in Dubman (2000).

Source: USDA, Economic Research Service (ERS) estimates based on the 2021 ARMS dairy version, jointly administered by USDA, ERS and USDA, National Agricultural Statistics Service.

Summing all costs (including operating, ownership, and opportunity and overhead costs), the total cost per 100 pounds of milk sold ranged from $19.14 for farms with at least 2,000 cows to $42.71 for farms with fewer than 50 cows. Economies of size for 2021 were due primarily to ownership costs and unpaid labor costs, with operating costs generally not contributing significantly to economies of size (figure 18). Differences in the total costs for dairy farms by size for each of the ARMS dairy survey years (2000, 2005, 2010, 2016, and 2021) are shown in figure 19. Note the decrease in total costs per 100 pounds of milk sold with increased farm size for all years, as well as the general increase in costs over time due to inflation.

Figure 18

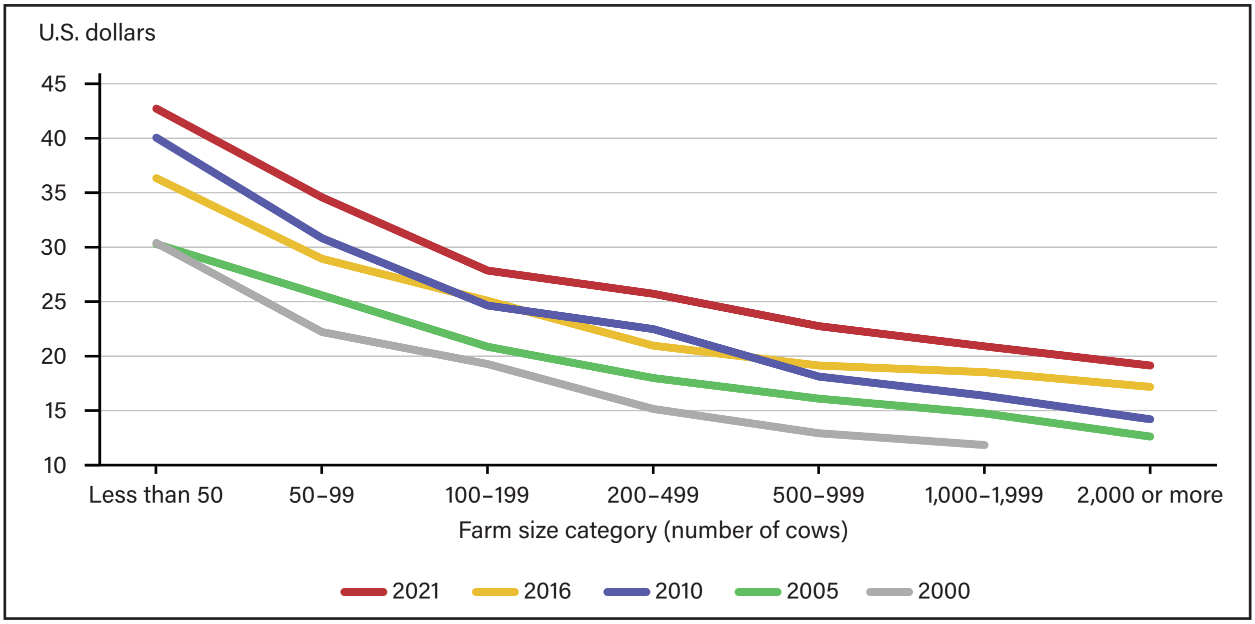
Mean operating, operating dairy farms (2021) and ownership, and total costs of producing 100 pounds of milk by farm size category, United States



Source: USDA, Economic Research Service (ERS) estimates based on the 2021 Agricultural Resource Management Survey dairy version, jointly administered by USDA, ERS and USDA, National Agricultural Statistics Service.

Figure 19

Mean total cost of producing 100 pounds of milk by farm size category, U.S. dairy farms, multiple years

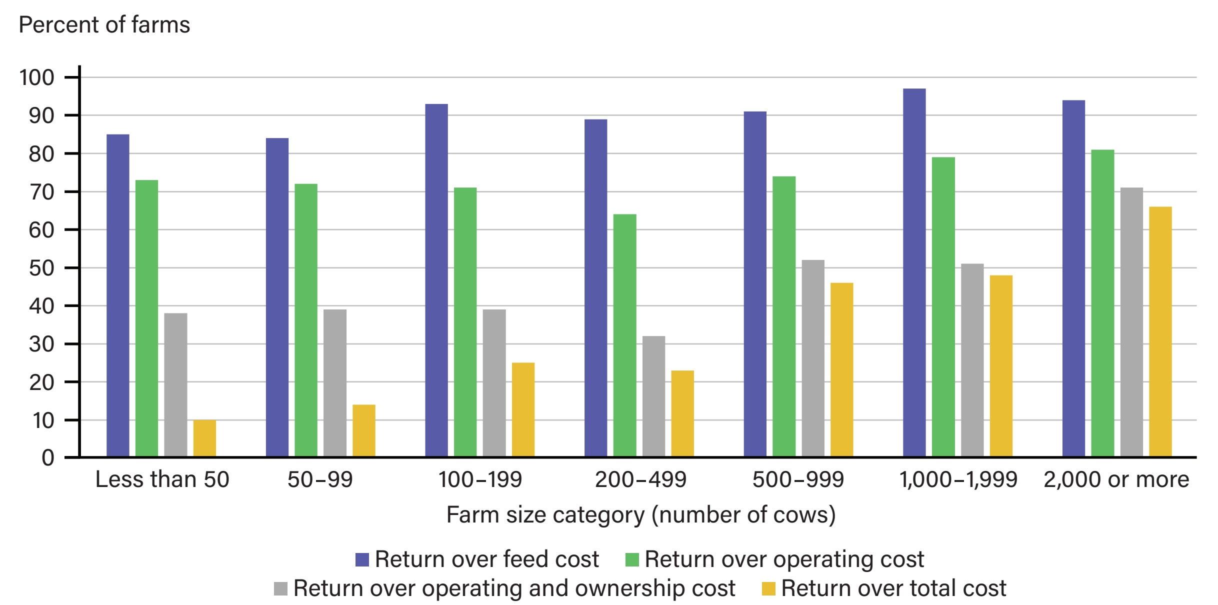


Note: For 2000, the 1,000–1,999 cows and 2,000 cows or more categories were combined into a 1,000 cows or more category to ensure sufficient observations for each category.

Source: USDA, Economic Research Service (ERS) estimates based on the 2000, 2005, 2010, 2016, and 2021 Agricultural Resource Management Survey dairy version, jointly administered by USDA, ERS and USDA, National Agricultural Statistics Service.

Four measures of profitability by farm size are presented in table 4. As farm size increased, net return over operating and ownership cost (as well as net return over total cost) increased. This increase is primarily because capital recovery and unpaid labor costs per unit of milk sold declined as farm size increased. The average net return over total cost ranged from -$19.95 per 100 pounds of milk sold for farms with less than 50 cows to $0.12 for farms with 2,000 cows or more. For the fewer than 50 cows size category (with an average net return over total cost of -$19.95), much of that deficit ($15.76) is attributed to opportunity and overhead costs. Government payments are not included. Note, however, that high-cost and low-cost farms were found in all size categories. Figure 20 shows that 10 percent of farms with fewer than 50 cows covered all costs. While 94 percent of farms with 2,000 cows or more covered feed costs, 6 percent of farms in this category did not.

Figure 20
Percentage of dairy farms with positive returns above costs, by farm size category, 2021

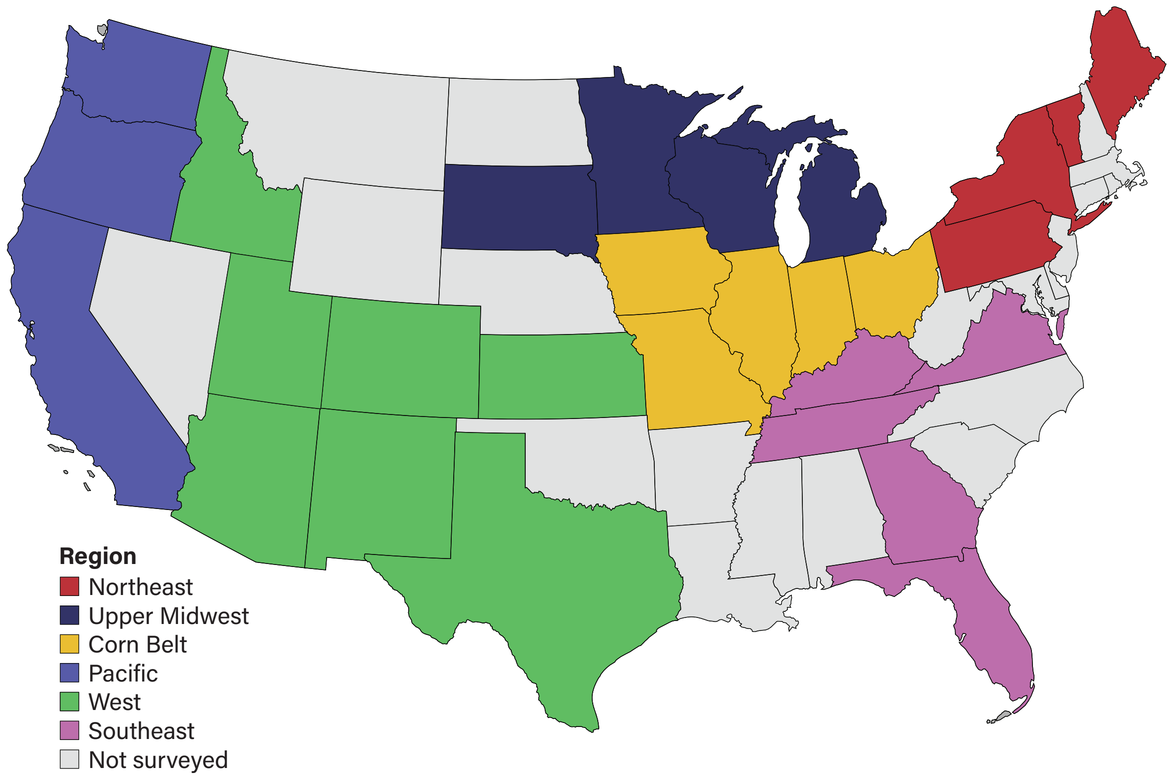


Source: USDA, Economic Research Service (ERS) estimates based on the 2021 Agricultural Resource Management Survey dairy version, jointly administered by USDA, ERS and USDA, National Agricultural Statistics Service.

Comparing Dairy Farms by Region

U.S. dairy farms differ by region for many reasons, including differences in climate and soil and milk and input prices. Six regions of U.S. dairy production are compared in this report, focusing on farm structure; adoption of technologies, management practices, and production systems; and farm costs and returns. These six regions were developed with the objective of identifying regions that produced milk under different farm structures and climatic conditions, ensuring sufficient observations for comparisons in each region. Regions compared include the Northeast, Corn Belt, Upper Midwest, Southeast, West, and Pacific. Figure 21 shows the surveyed States that comprise these regions. For this report, the Pacific and West regions together are sometimes referred to as the western United States, and all other regions together as the eastern United States.

Figure 21
U.S. dairy regions analyzed for this report



Note: Alaska and Hawaii are not shown because they were not surveyed in the ARMS dairy versions.

Source: USDA, Economic Research Service.

U.S. dairy farm structure and farmer demographic information by region for 2021 are shown in table 5. Farms with the highest average numbers of dairy cows were located in the Pacific and West regions, each averaging more than 900 cows per farm, while the smallest average number of cows was in the Corn Belt. Larger cow herds in the western regions do not, however, necessarily translate to more acres operated, as farms in the Pacific region differed only from the West in number of acres operated. Annual milk production per cow varied by region, ranging from 18,653 pounds in the Southeast to 24,419 pounds in the Pacific region. Farm diversification varied by region: The average percentage of a farm's value of production from milk ranged from 78 percent in the Corn Belt to 93 percent in the Pacific. Greater diversification of eastern relative to western farms is further noted by the higher percentage of farms in the Upper Midwest, Corn Belt, and Southeast producing corn than farms in the western regions; a greater percentage of farms in the eastern regions producing soybeans than farms in the West; and a greater percentage of farms producing hay in the eastern than the western regions. The percentage of the operator's household income coming from the farm was higher in the western regions than the eastern regions. This difference is likely related to the larger farm sizes in the western regions. The average operator age ranged from 51 years in the Corn Belt to 62 in the Pacific region.

Table 5

U.S. dairy farm structure and farm operator demographics, by region, 2021

	Northeast (a)	Upper Midwest (b)	Corn Belt (c)	Southeast (d)	West (e)	Pacific (f)
Percent of farms	29	33	22	4	5	7
Percent of milk sold	13	26	8	3	24	25
Number of cows	135[bdef]	215[acef]	118[bdef]	242[acef]	1,494[abcd]	934[abcd]
Acres operated	455[ce]	543[c]	349[abde]	548[c]	869[acf]	425[e]
Milk produced per cow (pounds)	21,335[bf]	23,469[ac]	20,967[bf]	18,653	22,119[f]	24,419[acf]
Percent of value of production from milk	86[cef]	86[ef]	78[aef]	83[ef]	92[a bcd]	93[abcd]
Percent of farms producing:						
Corn	71[be]	86[aef]	80[ef]	79[ef]	39[abcd]	41[bcd]
Soybeans	28[e]	30[e]	30[e]	25[e]	5[abcd]	0
Hay	75[bef]	58[acf]	72[bef]	72[ef]	47[acd]	24[abcd]
Small grains	26[d]	28[d]	25[d]	7[abc]	13	D
Debt-asset ratio	0.13[b]	0.22[ac]	0.16[b]	0.20	0.16	0.15
Percent operator household income from farm	61[ef]	72[ef]	73[ef]	70	91[abc]	93[abc]
Operator age (years)	55[c]	54[c]	51[abdf]	56[c]	54	62[c]
Percent of operators holding a 4-year college degree	8[e]	18	13	14	25[a]	38

D = insufficient data for disclosure.

Note: The lettered superscripts throughout the table denote statistically significant differences. A lettered superscript denotes that the item mean reported in a column is statistically significantly different from the item mean reported in the column identified by the superscript letter. Tests are expressed at a 90-percent confidence level. Tests were conducted using a delete-a-group jackknife variance estimator, with 30 replicates provided by the USDA, National Agricultural Statistics Service (NASS) for the Agricultural Resource Management Survey (ARMS) data, as discussed in Dubman (2000).

Source: USDA, Economic Research Service (ERS) estimates based on the 2021 ARMS dairy version, jointly administered by USDA, ERS and USDA, NASS.

Usage of technologies, management practices, and production systems by region is shown in table 6. Noteworthy differences include higher use of the following in the western regions than in the eastern regions: computerized feed delivery systems, individual cow production records, and computerized milking systems. Note that western farms were also larger than eastern farms, and larger farms were greater adopters of these technologies and management practices. In addition, southeastern farms had a relatively high percentage of farms using a nutritionist to design feed mixes or purchase rations and automatic take-offs, whereas the Corn Belt had a relatively high percentage of farms that were pasture-based and/or certified organic.

Table 6

Percentage of U.S. dairy farms adopting technologies, management practices, and production systems, by region, 2021

	Northeast (a)	Upper Midwest (b)	Corn Belt (c)	Southeast (d)	West (e)	Pacific (f)
Artificial insemination, embryo transplants, or sexed semen[1]	87^{cd}	85	74^{a}	65^{a}	82	65
Computerized feed delivery system	6^{ef}	9^{f}	5^{ef}	8^{f}	34^{ac}	30^{abcd}
Individual cow production records	62^{f}	59^{f}	57^{ef}	67^{f}	83^{c}	89^{abcd}
Milking units with automatic take-offs	31^{bde}	54^{a}	40^{de}	73^{ac}	65^{ac}	64
Nutritionist to design mixes or purchase feed	76	73	69^{d}	89^{c}	79	60
Parlor	38^{cdf}	48^{cdf}	68^{adf}	97^{abc}	D	94^{abc}
Milk three or more times per day	9^{e}	18^{e}	8^{e}	9^{e}	41^{abcd}	18
Computerized milking system	10^{e}	14^{e}	10^{e}	10^{e}	32^{abcd}	23
Pasture-based	16	12	25^{df}	10^{c}	17	6^{c}
Certified organic	18^{d}	13^{cd}	24^{bd}	2^{abc}	D	13

D = insufficient data for disclosure.

Note: The lettered superscripts throughout the table denote statistically significant differences. A lettered superscript denotes that the item mean reported in a column is statistically significantly different from the item mean reported in the column identified by the superscript letter. Tests are expressed at a 90-percent confidence level. Tests were conducted using a delete-a-group jackknife variance estimator with 30 replicates provided by the USDA, National Agricultural Statistics Service (NASS) for the Agricultural Resource Management Survey (ARMS) data, as discussed in Dubman (2000).

[1] A reviewer expressed concern at what appeared to be a lower than expected estimated adoption rate (65 percent) of artificial insemination, embryo transplants, and sexed semen in the Pacific region. Note that the adoption rate of 65 percent is not statistically different from the adoption rates in the other regions, so we cannot express confidence that the adoption rate for this technology in the Pacific region differs from the adoption rates for this technology in other regions. Also, note that the estimated adoption rate of 89 percent in the Pacific region for artificial insemination, embryo transplants, and sexed semen (using the 2016 ARMS dairy survey) was numerically higher than the 2021 ARMS dairy survey adoption rate.

Source: USDA, Economic Research Service (ERS) estimates based on the 2021 ARMS dairy version, jointly administered by USDA, ERS and USDA, NASS.

Comparing Costs and Returns by Region

Cost and return measures by U.S. region are shown in table 7. While total feed costs did not differ statistically, farms in the western regions had higher purchased feed costs than those in the eastern regions. Homegrown feed costs per 100 pounds of milk sold were generally lower in the western regions than those in the eastern regions. The Northeast and Corn Belt had higher grazed feed costs per 100 pounds of milk sold than the Upper Midwest, West, and Pacific regions. Overall, results suggest a higher dependency on purchased feeds in the western regions than in the eastern regions. Though operating costs did not differ significantly by region, ownership costs (which include capital recovery costs on buildings and equipment, taxes, and insurance) were lowest for farms in the western regions. This finding was likely due to the larger scale of the operations in western regions, with building and equipment costs being spread over greater output. Unpaid labor costs were lower in the western regions than in three other regions. This finding was likely the result of unpaid operator and family labor being spread across greater output on the larger farms in the western regions. Total costs were the lowest in the western regions. Primarily due to lower costs per unit of milk sold, net return over operating and ownership costs (as well as net return over total costs) were higher in the Pacific region than in the eastern regions. Net return over operating and ownership costs (as well as net return over total costs) were higher in the West than in one or more of the eastern regions.

Table 7

U.S. dairy farm costs and returns per 100 pounds of milk sold, by region, 2021

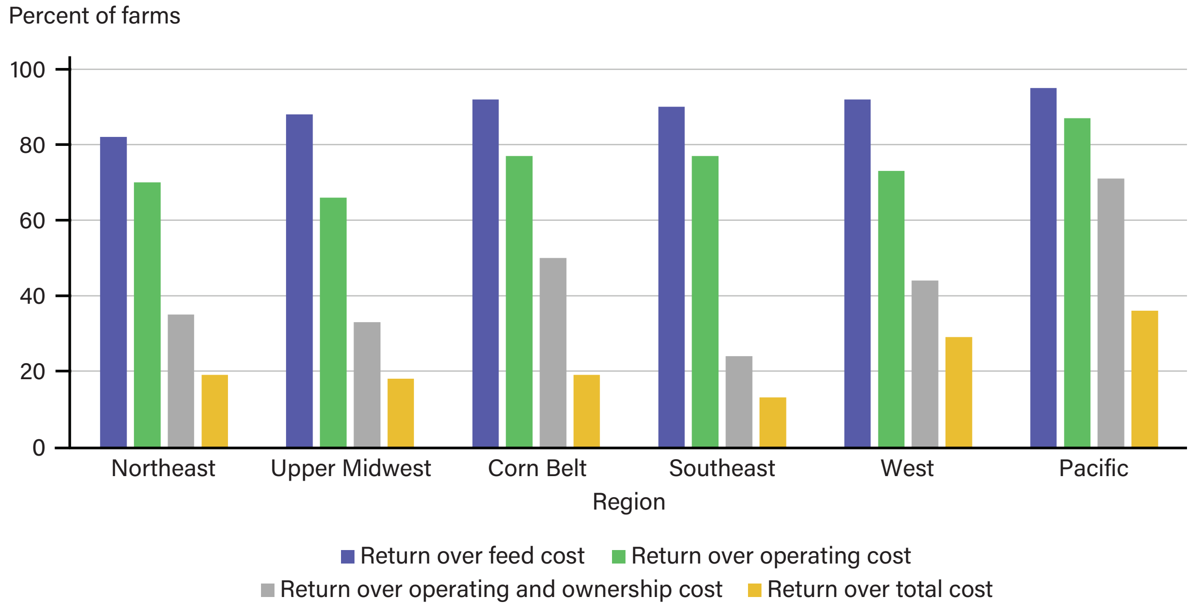
	Northeast (a)	Upper Midwest (b)	Corn Belt (c)	Southeast (d)	West (e)	Pacific (f)
Gross value of production						
Milk production	19.36[bcef]	18.66[a]	18.75[ae]	19.74[e]	17.28[acd]	18.58[a]
Animal sales and other	1.86[bf]	1.52[a]	1.78	1.74	1.58	1.54[a]
Gross value of production	21.23[bef]	20.18[a]	20.53[e]	21.48[e]	18.85[acd]	20.12[a]
Operating costs						
Purchased feed	5.82[ef]	6.45[ef]	6.03[ef]	6.96[ef]	10.15[abcd]	9.41[abcd]
Homegrown feed	6.39[bdef]	4.85[aef]	5.24[ef]	4.35[af]	2.50[abc]	2.53[abcd]
Grazed feed	0.06[bef]	0.02[ac]	0.07[bef]	0.05	0.02[ac]	0.02[ac]
Total feed cost	12.28	11.32	11.34	11.35	12.67	11.95
Cost of paid labor	1.89[c]	2.19[c]	1.36[abf]	2.50	1.62	2.12[c]
Cost of other operating inputs	3.86[ef]	3.52[ef]	3.51[ef]	3.21	2.65[abc]	2.23[abc]
Total cost of operating inputs	18.03	17.04	16.21	17.06	16.94	16.31
Total ownership costs	8.32[bcef]	4.44[a def]	5.12[a def]	6.82[bcef]	2.65[abcd]	2.72[abcd]
Opportunity and overhead costs						
Cost of unpaid labor	2.22[cef]	2.09[cef]	3.68[abdef]	1.88[cef]	0.29[abcd]	0.29[abcd]
Cost of land and overhead	0.73[e]	0.57[e]	0.65[e]	0.58[e]	0.34[a bcdf]	0.51[e]
Total opportunity and overhead costs	2.95[cef]	2.66[cef]	4.33[abdef]	2.45[cef]	0.62[abcd]	0.79[abcd]
Total cost	29.30[bef]	24.13[aef]	25.66[ef]	26.34[ef]	20.21[abcd]	19.82[abcd]
Net return measures						
Net return over feed cost	8.95[e]	8.86[e]	9.19[e]	10.13[e]	6.19[abcd]	8.17
Net return over operating cost	3.20	3.14	4.32	4.42	1.91	3.81
Net return over operating and ownership cost	-5.12[bcef]	-1.29[af]	-0.80[af]	-2.40[f]	-0.73[a]	1.10[abcd]
Net return over total cost	-8.07[bef]	-3.96[af]	-5.13[ef]	-4.86[ef]	-1.36[acd]	0.30[abcd]

Note: The lettered superscripts throughout the table denote statistically significant differences. A lettered superscript denotes that the item mean reported in a column is statistically significantly different from the item mean reported in the column identified by the superscript letter. Tests are expressed at a 90-percent confidence level. Tests were conducted using a delete-a-group jackknife variance estimator with 30 replicates provided by the USDA, National Agricultural Statistics Service (NASS) for the Agricultural Resource Management Survey (ARMS) data, as discussed in Dubman (2000).

Source: USDA, Economic Research Service (ERS) estimates based on the 2021 ARMS dairy version, jointly administered by USDA, ERS and USDA, NASS.

Though some regions had negative average net returns over operating and ownership costs, as well as negative average net returns over total costs, some dairy farms in all regions experienced positive net returns over all costs (figure 22). Likewise, though Pacific dairy farms experienced positive returns (on average) for all cost categories, some farms did not. Noteworthy statistically significant differences include the following: a higher percentage of Pacific farms experienced positive net returns above operating costs than Upper Midwestern farms; a higher percentage of Corn Belt and Pacific farms experienced positive net returns above operating and ownership costs than Upper Midwestern and Southeastern farms; and a higher percentage of western farms experienced positive net returns above operating and ownership costs than southeastern farms.

Figure 22
Percentage of dairy farms with positive returns above costs by region, 2021



Source: USDA, Economic Research Service (ERS) estimates based on the 2021 Agricultural Resource Management Survey dairy version, jointly administered by USDA, ERS and USDA, National Agricultural Statistics Service.

Estimating a Cost Function To Further Examine Economies of Scale and Efficiency

The use of ARMS data and advanced econometric methods to estimate a cost function allows for a deeper look at the cost structure and efficiency of U.S. dairy farms. While descriptive statistics shown earlier provide insights into the factors impacting production costs, estimation of the cost function allows for year and region to be controlled in analyzing the impacts of dairy farm size on production costs. For example, larger (smaller) dairy farms tend to be located in the western (eastern) States, but input prices also differ by region, making it difficult to fully analyze cost differences by farm size without a more sophisticated model. The stochastic cost frontier models are estimated using the costs and returns data from ARMS for 2000, 2005, 2010, 2016, and 2021, including only conventional, not certified organic, dairy farms. Certified organic farms are not included because their production methods are different, and they experience different prices for both output and some inputs, such as feed. Separate models were run for five different farm size categories, and we used another model that included all farm sizes with observations at the county level. Details on the model, parameter estimates, and specific results are found in the appendix.

Some key findings from the stochastic cost frontier models follow:

- Holding all else equal, a 1-percent increase in milk output resulted in a 0.49-percent increase in costs for dairy farms with 10–99 milk cows and a 0.83–percent increase in costs for dairy farms with at least 1,000 milk cows. Since increasing farm size by 1 percent increases costs by less than 1 percent for all farm sizes examined, further evidence of lower per-unit costs for larger farms (economies of scale) was found.

- Progressively lower input use per unit of output was found during the period 2000 to 2021 for both individual size category models and the aggregated county-level model. This finding provides evidence of increased productivity in converting inputs to output over the period.
- The average farm's estimated minimum cost of producing milk ranged between 79 and 83 percent of the average farm's actual cost of producing milk across the five selected herd size categories. This finding suggests that the average U.S. dairy farm could reduce costs by either procuring inputs at lower cost or decreasing the amounts of inputs, such as labor and materials that are required to produce a unit of milk.

Conclusion

The U.S. dairy industry has continued to experience significant structural change during the past two decades. The number of dairy farms has declined, while average farm sizes have increased. Shifts in the location of dairy production have continued, with Texas and Idaho increasing their share of production. Not only have dairy farms become larger, but they have become more specialized in dairy production, lowering their production of other farm commodities and depending more heavily on purchased rather than homegrown feeds. The usage of some advanced technologies, management practices, and production systems has also increased over the past decade as milk productivity per cow has increased. Larger dairy farms have tended to be more specialized in dairy production than smaller dairy farms and are the greater adopters of the most advanced technologies, management practices, and production systems. Furthermore, larger dairy farms generally incur lower costs per unit of milk produced—with labor, buildings, and equipment costs having a particularly large impact on cost by size class.

Though total costs exceed returns for the average smaller dairy farm, survey results show that some farms of all sizes cover total costs, while other farms do not. This finding is at least partially attributed to the greater cost efficiency of some farms than others. There are also regional differences in U.S. dairy production: Relative to farms in the eastern United States, farms in the western United States tend to be larger and greater adopters of advanced technologies, management practices, and production systems.

References

Berry, D. P. (2021). Beef-on-dairy—The generation of crossbred beef × dairy cattle. *Journal of Dairy Science,* 104(4), 3879–3819.

Culbertson, R. (February 2023). *Beef on dairy*. eBeef.org. Retrieved October 13, 2023.

Dubman, R. W. (2000). *Variance estimation with USDA's farm costs and returns surveys and Agricultural Resource Management Surveys* (Report No. AGES 00-01). U.S. Department of Agriculture, Economic Research Service.

Gillespie, J., Nehring, R., Hallahan, C., Sandretto, C., & Tauer, L. (2010). Adoption of recombinant bovine somatotropin and farm profitability: Does farm size matter? *AgBioForum,* 13(3), 251–262.

Khanal, A., Gillespie, J., & MacDonald, J. (2010). Adoption of technology, management practices, and production systems in U.S. milk production. *Journal of Dairy Science,* 93(12), 6012–6022.

Kumbhakar, S. C., & Lovell, C. A. K. (2000). *Stochastic frontier analysis*. Cambridge University Press.

MacDonald, J. M., Cessna, J., & Mosheim, R. (2016). *Changing structure, financial risks, and government policy for the U.S. dairy industry* (Report No. ERR-205). U.S. Department of Agriculture, Economic Research Service.

MacDonald, J. M., Law, J., & Mosheim, R. (2020). *Consolidation in U.S. dairy farming* (Report No. ERR-274). U.S. Department of Agriculture, Economic Research Service.

MacDonald, J. M., O'Donoghue, E., McBride, W.D., Nehring, R., Sandretto, C., & Mosheim, R. (2007). *Profits, costs, and the changing structure of dairy farming* (Report No. ERR-47). U.S. Department of Agriculture, Economic Research Service.

McBride, W. D., & Greene, C. (2009). *Characteristics, costs, and issues for organic dairy farming* (Report No. ERR-82). U.S. Department of Agriculture, Economic Research Service.

McBride, W. D., Short, S., & El-Osta, H. (2004). The adoption and impact of bovine somatotropin on U.S. dairy farms. *Review of Agricultural Economics,* 25(4), 472–488.

Njuki, E. (2022). *Sources, trends, and drivers of U.S. dairy productivity and efficiency* (Report No. ERR-305). U.S. Department of Agriculture, Economic Research Service.

Short, S. D. (2004). *Characteristics and production costs of U.S. dairy operations* (Report No. SB-974-6). U.S. Department of Agriculture, Economic Research Service.

Stefanides, Z., & Tauer, L.W. (1999). The empirical impact of bovine somatotropin on a group of New York dairy farms. *American Journal of Agricultural Economics,* 81(1), 95–102.

Stewart, H., Kuchler, F., Dong, D., & Cessna, J. (2021). *Examining the decline in U.S. per capita consumption of fluid cow's milk, 2003–18* (Report No. ERR-300). U.S. Department of Agriculture, Economic Research Service.

U.S. Department of Agriculture, Agricultural Marketing Service. (2023). *Federal milk marketing orders*. Retrieved October 13, 2023.

U.S. Department of Agriculture, Animal Plant and Health Inspection Service. (2022). *Dairy 2014: Trends in dairy cattle health and management practices in the United States, 1991–2014* (Report No. 5). (2022). Veterinary Services, National Animal Health Monitoring System, November.

U.S. Department of Agriculture, Economic Research Service. (2023). *Commodity costs and returns data*.

U.S. Department of Agriculture, Economic Research Service. (2024). *Farm Household Income* and *Characteristics Data.*

U.S. Department of Agriculture, Economic Research Service and USDA, National Agricultural Statistics Service. (2000, 2005, 2010, 2016, 2021). *Agricultural resource management survey, phase 3 dairy survey*.

U.S. Department of Agriculture, Farm Service Agency. (2024). *2023 Dairy Margin Coverage Program Enrollment Report by State*—March 4.

U.S. Department of Agriculture, Farm Service Agency. (2022). *Dairy Margin Coverage program*. Fact Sheet.

U.S. Department of Agriculture, National Agricultural Statistics Service. (2000–2021). *Agricultural prices*.

U.S. Department of Agriculture, National Agricultural Statistics Service. (2002, 2007, 2012, 2017). *Census of agriculture*.

U.S. Department of Agriculture, National Agricultural Statistics Service. (2017, 2022). *Certified organic survey, 2016, 2021 summary.*

U.S. Department of Agriculture, National Agricultural Statistics Service. (2005–2024). *Milk production*. February issues, 2005–2024; March issue, 2019.

U.S. Department of Agriculture, National Agricultural Statistics Service. (2002–2022). *Milk production, disposition, and income 2002, 2016, 2021, and 2022 summary.* April.

U.S. Department of Agriculture, Natural Resources Conservation Service. (2023). *Programs and initiatives*. Retrieved October 13, 2023.

U.S. Department of Agriculture, Risk Management Agency. (2019). *Dairy revenue protection fact sheet*, April.

U.S. Department of Agriculture, Risk Management Agency. (2022). *Livestock gross margin insurance dairy cattle*. Fact Sheet, April.

Wiggins, G. R. & Carrillo, J. A. (2022). Genomic selection in United States dairy cattle. *Frontiers in genetics,* 13, 994466. https://doi.org/10.3389/fgene.2022.994466.

Appendix: Estimating a Cost Function

Stochastic cost frontier models were estimated using costs and returns data derived from the Agricultural Resource Management Survey (ARMS) dairy version for 2000, 2005, 2010, 2016, and 2021. The models used only conventional, not certified organic, dairy farms. The estimated model is the following:

$$\ln E_{it} = \beta_o + \beta_y \ln y_{it} + \sum_{k=1}^{K} \beta_k \ln \widetilde{w}_{kit} + \tau_t + \gamma_i + v_{it} + \eta_{it}$$

which is a Cobb-Douglas cost function where the dependent variable, $\ln E_{it}$, measures the log of total expenditures on inputs for farm i in time period t, $\ln y_{it}$ measures the log of milk output, and $\ln \widetilde{w}_{kit}$ are the logs of the corresponding input k prices, adjusted by a numeraire. Input prices used were price of home-grown and purchased feed, price of unpaid labor, price of hired labor, price of material inputs (i.e., veterinary, and custom work), and capital (i.e., depreciation, taxes, and interest rates paid). The price of capital, or the per unit cost of capital, was chosen as the numeraire. That is, the price of capital was used to divide the cost and other prices before estimation. Thus, $\widetilde{w}_1$ is the unit price of unpaid labor relative to the price of capital, $\widetilde{w}_2$ is the price of paid labor relative to the unit price of capital, $\widetilde{w}_3$ is the price of feed relative to the unit price of capital, and $\widetilde{w}_4$ is the unit price of material inputs relative to the unit price of capital. All monetary values were deflated using 2011 agricultural price indices provided by USDA, National Agricultural Statistics Service (NASS) Agricultural Prices reports. Furthermore, τ_t and γ_i capture unobserved time-varying and time-invariant factors that affect cost, such as regions used in the model, which are shown in figure 21. Finally, β_o, β_y, and β_k are parameters to be estimated.

The composed error term comprises a statistical error component v_{it}, and a nonnegative cost inefficiency component η_{it}, with distributional properties, $v_{it} \sim N(0, \sigma_v^2)$ and $\eta_{it} \sim N^+(0, \sigma_\eta^2)$, respectively. The estimation was conducted using maximum likelihood methods, and the estimated coefficients can be interpreted as marginal effects. Kumbhakar and Lovell (2000) provided further information on the specifics of estimating cost functions using stochastic frontier analysis. In total, 6 cost frontier models are presented, 1 for each of 5 size categories: less than 100 cows, 100–199 cows, 200–499 cows, 500–999 cows, and 1,000 or more cows, and a county-level national model. The separate models by size category allowed for examination of each of the farm sizes individually, where the micro-level unit was the farm. The county-level national model was a pseudo-panel that aggregated dairy production at the county-level to estimate cost and efficiency results by county. The model allowed for the examination at the national level across size categories, where county was the micro-level unit and counties had different average operation sizes.

Appendix tables A.1, A.2, and A.3 present cost frontier model results. Some key findings are:

- Appendix table A.1 results indicate that marginal costs of milk production, $\hat{\beta}_y$, increase with herd size. Examining results for the different herd size categories, for example, all else held equal, a 1-percent increase in milk production resulted in a 0.834-percent increase in costs for dairy farms with at least 1,000 milk cows. These results show evidence of scale economies in all size classes: increasing farm size by 1 percent increases costs by less than 1 percent.

- Positive coefficients for $\beta_1 - \beta_4$ indicate increased prices for the respective inputs relative to the price of capital increase costs. Mostly negative coefficients for $\tau_1 - \tau_4$ indicate costs for the referenced year decreased relative to base year 2000. For example, for the 1,000 cows or more category, costs in 2005 were 9.9 percent lower than in 2000. Negative coefficients for $\tau_1 - \tau_4$ were consistent with lower input per unit of output over time. Mostly negative coefficients for $\gamma_1 - \gamma_5$ indicate costs for the referenced region decreased relative to the base region, the Southeast. For example, for the 1,000 cows or more category, Northeastern dairy costs were 15.5 percent lower than those in the Southeast.

- From appendix table A.2, the average farm's minimum cost of producing milk ranged between 78.9 and 82.8 percent of the average farm's actual cost of producing milk across the various herd sizes. For example, the average dairy farm with 1,000 or more milk cows has the potential to lower costs by $1/0.795 - 1 \approx 25.7$ percent without reducing milk output.

- From appendix table A.3, where the unit level of analysis was the county, the results reveal, all else held equal, that the marginal cost of milk production, $\hat{\beta}_y$, for the average county was 79.1 percent. In other words, a 1-percent increase in milk production would result in a 0.791-percent increase in cost. The inverse of the marginal cost, $1/\hat{\beta}_y$, represents an estimate of returns to scale. From table 7, the estimates reveal that returns to scale was $1/0.791 \approx 1.26$, indicating increasing returns to scale for the average county, since 1.26 is greater than 1. The interpretation is that milk output increases at a greater proportion than input as input is increased.

- Consistent with the separate size category analyses, the county-level analysis showed positive coefficients for $\beta_1 - \beta_4$, indicating that increased prices for the respective inputs relative to the price of capital increased costs. Negative coefficients for $\tau_1 - \tau_4$ indicate that costs for the referenced year decreased relative to the base year, 2000. For example, costs in 2021 were 11 percent lower than in 2000, consistent with increased productivity, or lower input per unit of output over time. Negative coefficients for γ_2, γ_3, and γ_5 indicate lower costs for the Upper Midwest, Corn Belt, and West, relative to the base region, the Southeast.

- Cost efficiency refers to the ratio of the minimum feasible cost to observed expenditures. A fully cost-efficient farm produces the maximum amount of milk possible at the lowest possible cost. The cost efficiency for the average county was 77.2 percent (appendix table A.4). In other words, the average county could have reduced actual costs by $1/0.772 - 1 \approx 29.5$ percent without reducing milk output.

Appendix table A.1

Cost frontier model coefficient estimates by herd size, U.S. conventional dairy farms

	Herd size, milk cows	≥1,000 cows		500–999 cows		200–499 cows		100–199 cows		<100 cows	
Parameter/variable		Coefficient	(Standard error)	Coefficient	(Standard error)	Coefficient	(Standard error)	Coefficient	(Standard error)	Coefficient	(Standard error)
β_0	Constant	2.082***	(0.275)	3.286***	(0.421)	4.104***	(0.227)	5.310***	(0.204)	4.923***	(0.105)
β_y	y (milk)	0.834***	(0.020)	0.671***	(0.037)	0.601***	(0.021)	0.475***	(0.021)	0.489***	(0.011)
β_1	w1 (unpaid labor)	0.152*	(0.078)	0.144**	(0.073)	0.123**	(0.053)	0.314***	(0.046)	0.459***	(0.037)
β_2	w2 (paid labor)	0.717***	(0.079)	0.574***	(0.078)	0.632***	(0.057)	0.513***	(0.048)	0.408***	(0.038)
β_3	w3 (feed)	0.007	(0.007)	0.026***	(0.006)	0.007	(0.005)	0.003	(0.006)	-0.005	(0.006)
β_4	w4 (materials)	0.103***	(0.021)	0.186***	(0.022)	0.211***	(0.017)	0.164***	(0.013)	0.110***	(0.010)
τ_1	2005	0.099*	(0.055)	0.011	(0.044)	0.035	(0.032)	0.045*	(0.025)	0.019	(0.021)
τ_2	2010	-0.010	(0.057)	-0.020	(0.049)	-0.011	(0.034)	-0.062**	(0.025)	-0.050***	(0.019)
τ_3	2016	-0.027	(0.057)	-0.080*	(0.048)	-0.185***	(0.035)	-0.244***	(0.027)	-0.211***	(0.023)
τ_4	2021	0.074	(0.064)	-0.035	(0.059)	-0.037	(0.044)	-0.073**	(0.033)	0.026	(0.030)
γ_1	Northeast	-0.155**	(0.061)	0.024	(0.051)	-0.064*	(0.031)	-0.050**	(0.025)	-0.025	(0.022)
γ_2	Upper Midwest	-0.270***	(0.057)	-0.067	(0.048)	-0.142***	(0.031)	-0.147***	(0.025)	-0.095***	(0.023)
γ_3	Corn Belt	-0.343***	(0.062)	-0.123**	(0.054)	-0.168***	(0.032)	-0.082***	(0.023)	-0.093***	(0.022)
γ_4	Pacific	-0.301***	(0.047)	-0.005	(0.041)	-0.079***	(0.028)	-0.063**	(0.028)	0.034	(0.035)
γ_5	West	-0.260***	(0.049)	0.003	(0.044)	-0.018	(0.030)	-0.120***	(0.029)	-0.031	(0.036)
σ_v	Sigma (v)	0.213***	(0.014)	0.199***	(0.014)	0.217***	(0.011)	0.205***	(0.011)	0.237***	(0.009)
σ_η	Sigma (η)	0.289***	(0.031)	0.293***	(0.028)	0.234***	(0.027)	0.263***	(0.024)	0.296***	(0.019)
σ^2	Sigma squared	0.129***	(0.014)	0.125***	(0.013)	0.102***	(0.009)	0.111***	(0.010)	0.143***	(0.009)
λ	Lambda	1.360***	(0.042)	1.471***	(0.039)	1.079***	(0.036)	1.282***	(0.034)	1.250***	(0.027)
	Log likelihood	-64.74		-44.20		-59.92		-78.63		-406.49	
	Number of farms	542		516		955		1,252		2,060	

Note: The significance is denoted as: *** = p<0.01, ** = p<0.05, and * = p<0.1. The dependent variable is the log of total expenditures. The base year for year variables is 2000. The base region for regional variables is the Southeast. Conventional dairy farms are farms that are not certified organic.

Source: USDA, Economic Research Service (ERS) using data from the Agricultural Resource Management Survey dairy versions in 2000, 2005, 2010, 2016, and 2021.

Appendix table A.2
Average cost efficiency estimates by herd size, U.S. conventional dairy farms

Herd size, (number of cows)	Observations	Mean	Standard deviation	Minimum	Maximum
≥1,000	542	0.795	0.084	0.238	0.947
500–999	516	0.794	0.088	0.197	0.952
200–499	955	0.828	0.064	0.370	0.951
100–199	1,252	0.810	0.078	0.409	0.951
<100	2,060	0.789	0.083	0.179	0.964

Source: USDA, Economic Research Service using data from the Agricultural Resource Management Survey dairy versions in 2000, 2005, 2010, 2016, and 2021.

Appendix table A.3
Cost frontier model parameter estimates at the county-level, U.S. conventional dairy farms

Parameter/variable		Coefficient	Standard error
β_0	Constant	2.507***	(0.059)
β_y	y (milk)	0.791***	(0.005)
β_1	w1 (unpaid labor)	0.253***	(0.039)
β_2	w2 (paid labor)	0.639***	(0.040)
β_3	w3 (feed)	0.011**	(0.005)
β_4	w4 (materials)	0.091***	(0.007)
τ_1	2005	-0.008	(0.021)
τ_2	2010	-0.107***	(0.021)
τ_3	2016	-0.274***	(0.022)
τ_4	2021	-0.110***	(0.027)
γ_1	Northeast	-0.019	(0.023)
γ_2	Upper Midwest	-0.124***	(0.022)
γ_3	Corn Belt	-0.107***	(0.021)
γ_4	Pacific	-0.034	(0.025)
γ_5	West	-0.049*	(0.024)
σ_v	Sigma (v)	0.236***	(0.007)
σ_η	Sigma (η)	0.326***	(0.016)

Note: The significance is denoted as: *** = p<0.01, ** = p<0.05, and * = p<0.1. The dependent variable is the log of total expenditures. The base year for year variables is 2000. The base region for regional variables is the Southeast.
Source: USDA, Economic Research Service using data from the Agricultural Resource Management Survey dairy versions in 2000, 2005, 2010, 2016, and 2021.

Appendix table A.4
Cost efficiency estimates at the county-level, U.S. conventional dairy farms

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
Cost efficiency	2,420	0.772	0.093	0.117	0.961

Source: USDA, Economic Research Service using data from the Agricultural Resource Management Survey dairy versions in 2000, 2005, 2010, 2016, and 2021.