Dairy farm growth and the welfare impacts of a growth-based production quota on different farm size groups

by

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Abstract

Low milk prices have led to divisive discussions of production controls as a potential solution among dairy farmers and industry groups. A growth-based production quota is one idea that has gained some support among farmers. The purpose of this thesis is to analyze the potential impacts of a growth-based production quota on different dairy farm size groups.

To understand if small or large farms are growing faster, the relationship between a dairy farm's initial size and their growth rate is analyzed. I use county-level information on the number of dairy farms and milk cows from the USDA's Census of Agriculture. A statistically significant and positive relationship is found to exist between initial farm size and the growth rate in farm size over the past twenty years, which suggests that the larger a farm is, the faster they are growing their farm size and therefore milk production. Additional data from the USDA ARMS provides supporting evidence that larger dairy farms are growing at faster rates than smaller dairy farms in both 2000 and 2016. However, the difference in the growth rate was smaller in 2016 than in 2000.

An equilibrium displacement model (EDM) is developed to estimate the impacts of a growth-based production quota. I consider scenarios where the production quotas range from requiring a 2 percent decrease in milk production to allowing for a 2 percent increase in milk production on each farm. Farms of all sizes are found to benefit in terms of producer welfare under all scenarios. Small farms benefit slightly more because they have smaller growth rates, but the difference between farm size groups is very small. Even when using very elastic estimates of the demand elasticity for fluid milk, all producer groups are found to benefit from the quota, though the benefit is much smaller. Under all the quota scenarios, the market price for fluid milk increases, therefore consumers are negatively impacted.

Despite the benefits expected under the quota, some dairy farmers may still be opposed to a production control due to concerns over farm expansion potential, potential retaliatory trade actions by other countries, and potential consumer blowback due to higher market prices.

Table of Contents

List of Figures

List of Tables

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My success during my graduate career would not have been possible without the unwavering moral, emotional, and professional support of my dear friends Hannah, Chelsea, Raymond, Christina, and Bailey. I would like to also recognize the rest of my classmates who played an integral role in supporting me throughout my coursework here at K-State.

Dedication

For my cousin Mathilde who has been like a sister to me and has always believed in me and my ability to accomplish anything I put my mind to.

Chapter 1 - Introduction

Expansion of milk production has led to low market prices for dairy farmers and is a common issue for a fundamental reason. When prices rise, producers increase their herd/farm sizes and production, but once prices fall back down, they are unable to easily cut back production. Large levels of production have weighed on fluid milk prices in recent years, creating financially challenging conditions for dairy farmers. Coinciding with difficult fluid milk prices has been a significant decline in the number of dairy farms in the United States. As a result of these industry conditions, production control has become a hot topic of discussion among those in the dairy sector.

The idea of some form of production control strongly divides dairy industry groups and even dairy farmers themselves. Some industry groups are in favor of a government-mandated system to limit the growth in fluid milk production while others oppose any sort of system not based in the free market. Some dairy farmers look to Canada's supply management system with envy and hope for something similar in the U.S. while others do not want the government to tell them how much they can or cannot produce.

Understanding how dairy farmers, and dairy farmers of different sizes, would be impacted by a production control is important for two reasons. One, it can provide insightful information to dairy farmers so they can make an informed decision on whether or not a growth-based production control would be a benefit. Two, it can provide policymakers with valuable information to use in designing an effective growth-based production control if that is something that is desired by their dairy farmer constituents.

The purpose of this thesis is to assess the impacts of a growth-based production quota for the United States' dairy sector on different farm size groups. County-level data from the United

States Department of Agriculture (USDA)'s quinquennial Ag Census and aggregated farm-level data from the Agricultural Resource Management Survey (ARMS) from the USDA are used to first determine how different farm size groups have been growing over the past twenty years across different regions and to determine what the distribution of dairy farm growth has looked like over the same period. A primary research objective is to develop a partial-equilibrium model to assess the welfare impacts of different growth-based production control scenarios on the U.S. dairy sector as a whole and on different farm size groups.

To quantify the relationship between farm size and growth in farm size, regressions are run using the county-level Ag Census data on farm and milk cow numbers across the 1997, 2002, 2007, 2012, and 2017 Ag Census data. To determine how individual farms of different sizes have been growing within annual time frames, growth rates are calculated using aggregated farm-level information on beginning and ending milk cow inventories from a special tabulation of the 2000 and 2016 ARMS.

A positive relationship is found to exist between initial farm size and growth in farm size, meaning that as the initial size of a farm increases, the rate of growth in size for that farm increases. Based on the 2000 and 2016 ARMS data, the larger farm size groups had more positive growth rates than the smaller farm size groups. Both of these results suggest that larger dairy farms have been growing at a greater pace than smaller dairy farms.

An equilibrium displacement model (EDM) is developed to model the U.S. dairy sector. In the model, fluid milk is the sole product produced and the supply of milk is disaggregated into five different supply curves for five different farm size groups (farms with 20-49 milk cows, 50-99 milk cows, 100-199 milk cows, 200-499 milk cows, and 500 and more milk cows). Using reasonable parameter values from the literature or from conditions experienced by the industry in recent years, simulations of 17 different quota scenarios are run using both highly inelastic and slightly inelastic demand elasticities for fluid milk as well as both 2000 and 2016 farm growth rates.

The results of the EDM simulations show that under a growth-based production control ranging from requiring a 2 percent annual decrease in milk production to allowing a 2 percent annual increase in milk production, all farm size groups would benefit while consumers are negatively affected under seventeen quota scenarios due to the market price for fluid milk rising.

Some dairy farmers and producer groups may be opposed to any form of production control for a couple of different reasons. One potential reason is concern regarding farm expansion potential under a production control. If a farm has been rapidly expanding their milk cow herd size and production by a rate of 5 percent annually, then a mandatory policy comes into effect telling them they are limited to annual growth of 2 percent, it is understandable why that farmer would strongly oppose the policy. Many farmers who have been rapidly growing would likely be opposed to a production control for the U.S. dairy sector. Smaller farms or those who have been growing less would likely be in favor of a production control because they would get to reap the benefit of the higher market price without having to reduce their production or scale back their growth. Additionally, with the quota, the U.S. would likely have to impose a tariff on dairy product imports to limit consumers from switching to cheaper options from other countries. Producers may be concerned that this could result in retaliatory tariffs on U.S. dairy product exports. Another potential reason for opposition to a production control policy among dairy farmers is the concern that the higher market price could negatively impact consumers' views of the dairy industry which could potentially lead to opposition to a future policy that supports dairy farmers. In traditional dairy areas where farms have been around for a longer time and are likely growing less, farmers are likely to want their elected officials to support a growth-based production control to raise market prices while farmers in newer dairy areas where farms are younger and rapidly growing are likely to oppose any form of production control so they can continue expanding their herds and production.

Primary limitations of the research presented in this thesis include the data utilized being aggregated at some level rather than farm-specific as well as a relatively simplified model of the U.S. milk market that does factor in how the international market affects U.S. dairy farmers and consumers.

Chapter 2 - Industry Context for the U.S. Dairy Sector

The U.S. dairy sector comprises feed suppliers, farms that milk cows, milk processors, retailers, and ultimately consumers both here domestically and around the world. Some farms produce their own feed for their cattle while other farms purchase feed such as dried distiller grains (DDGs) from suppliers. A farm may sell their male (bull) calves shortly after birth while other farms raise their bull calves as either steers for beef production or as bulls for breeding.

Dairy farming is known for its economies of scale. As farmers increase their level of production, their cost of producing a unit of milk falls. This is displayed in Figure 1.1 (below) which illustrates data from the United States Department of Agriculture (USDA)'s cost of milk production estimates. As can be seen in the figure, the total costs per hundredweight (cwt) of milk falls as the farm size increases.

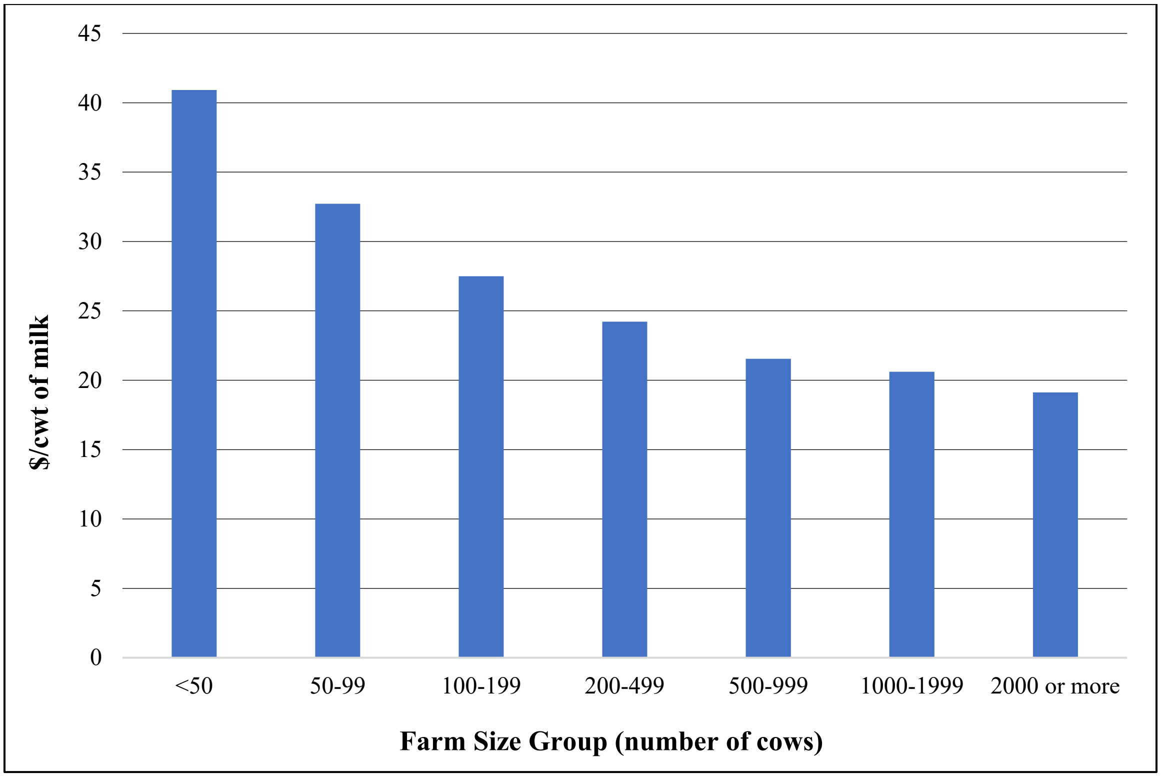

Figure 2.1 – Production Cost ($/cwt) of Milk by Farm Size in 2019 (data from USDA)

The evident economies of scale in dairy have led to substantial consolidation and increasing farm size for several decades. The dairy sector in the United States looks vastly different today than it did twenty years ago. In 2000, the U.S. had 105,250 operations with milk cows and 9.2 million milk cows for an average farm size of a little over 87 head (USDA 2001). Twenty years on, in 2019, the U.S. had 34,187 dairy farms (a 68% decrease) and 9.3 million milk cows for an average farm size of just over 272 head (a 213% increase) (USDA 2020). Figure 1.2 (below) illustrates how the average dairy farm size has increased more than 260 percent since 1997. In 2019, the top milk producing states were California, Wisconsin, Idaho, New York, and Texas (USDA 2020).

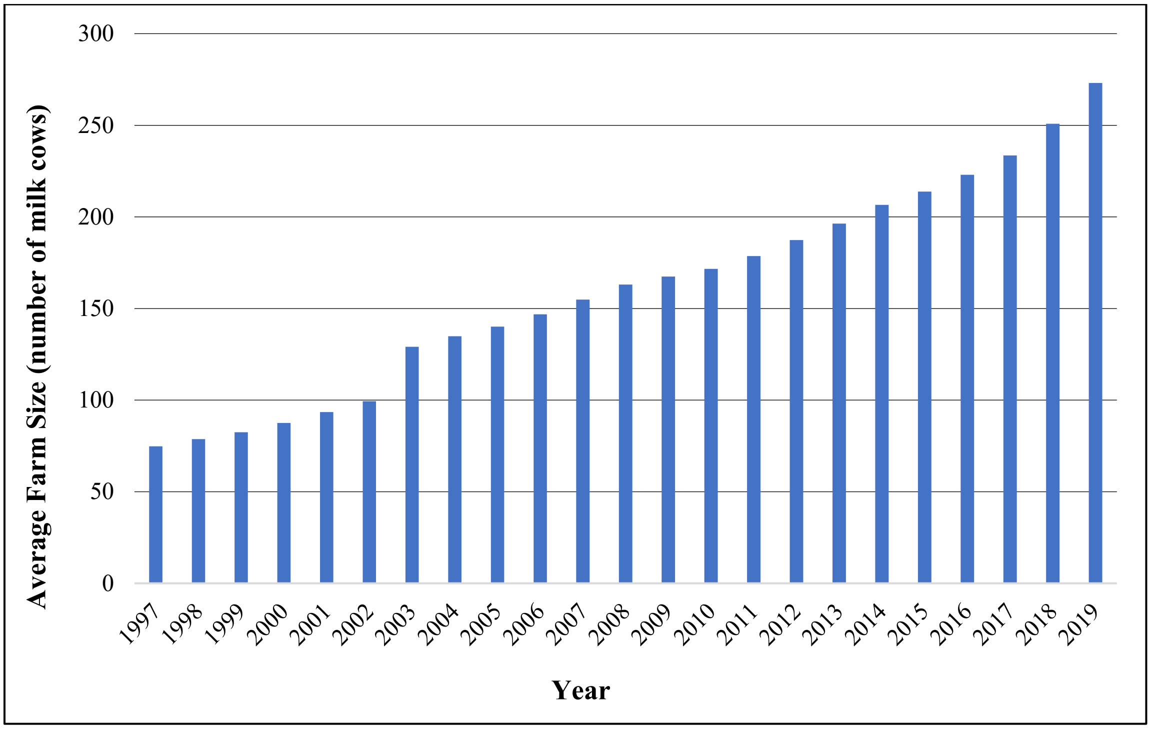

Figure 2.2 – Change in Average U.S. Dairy Farm Size Since 1997 (data from USDA)

The dairy sector in Kansas has also seen substantial changes over the past twenty years. In 2000, Kansas had 1,300 milk cow operations with a total of 91,000 cows for an average farm size of 70 head producing 1.5 billion pounds of milk (USDA 2001). In 2019 the state had 270 licensed dairy herds (a 79 percent decrease) with 163,000 milk cows (a 79 percent increase) for an average farm size of 604 head (a 763 percent increase) producing 3.8 billion pounds of milk (a 153 percent increase) (USDA 2020).

While the average dairy farm size has been climbing, farms range in size from less than 10 milking cows to thousands of milking cows and are present in all 50 states. Some milk processors focus on producing dairy products such as cheese or butter while others focus primarily on processing and bottling milk. Dairy products produced by processors are then transported throughout the United States and around the world to be consumed. Figure 1.3 (below) illustrates the general flow of the U.S. dairy supply chain.

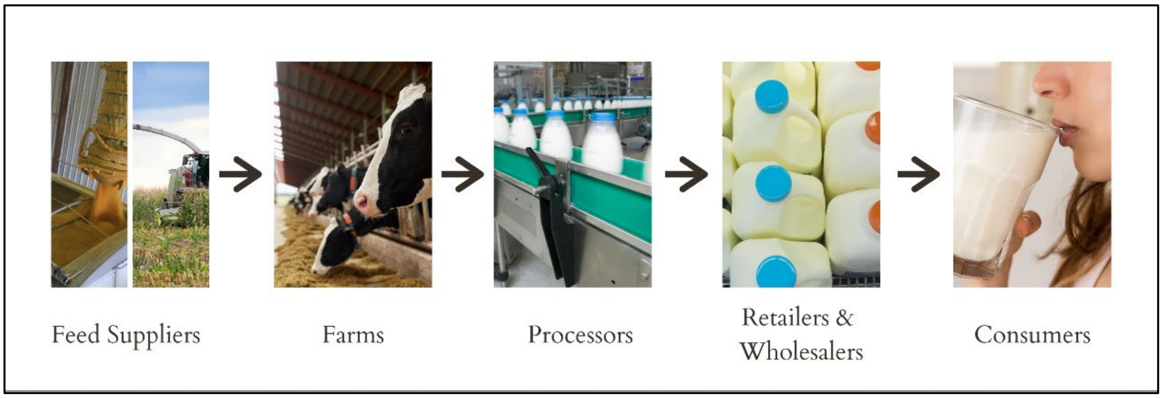

Figure 2.3 – Main Steps in the U.S. Dairy Supply Chain

International trade is an important component of the dairy sector. In 2019, the U.S exported more than 2 billion pounds of dairy products. Figure 2.4 (below) displays the imports and exports for four major dairy products. Note that fluid milk is not included as its short shelf life requires it to be transformed into other products to be able to be traded.

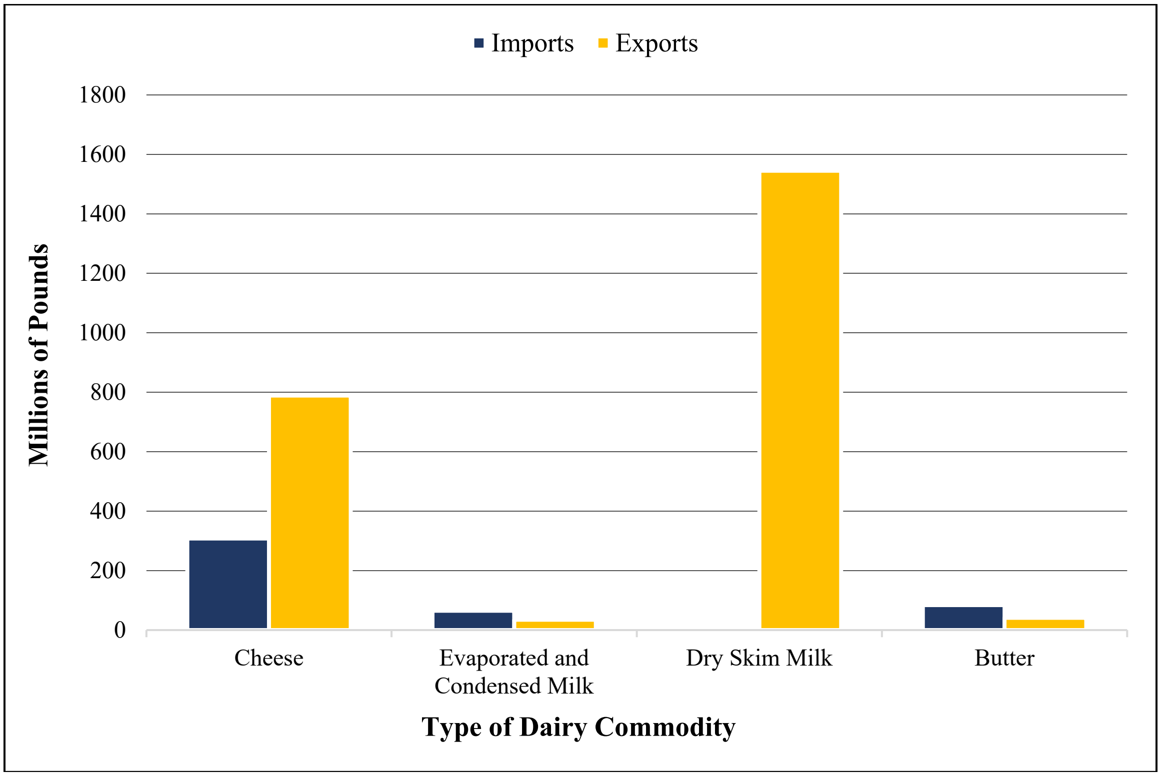

Figure 2.4 – Dairy Imports and Exports (millions of lbs.) in 2019 (data from USDA)

Figure 2.5 (below) shows the amount of both dairy exports and imports from 1997 to 2019; note that the U.S. has been a net exporter of dairy products for the past 9 years. Note that the numbers are different in the below figure since the unit is millions of pounds of milk-fat equivalent while the units in Figure 2.4 (above) are millions of pounds for all the dairy products.

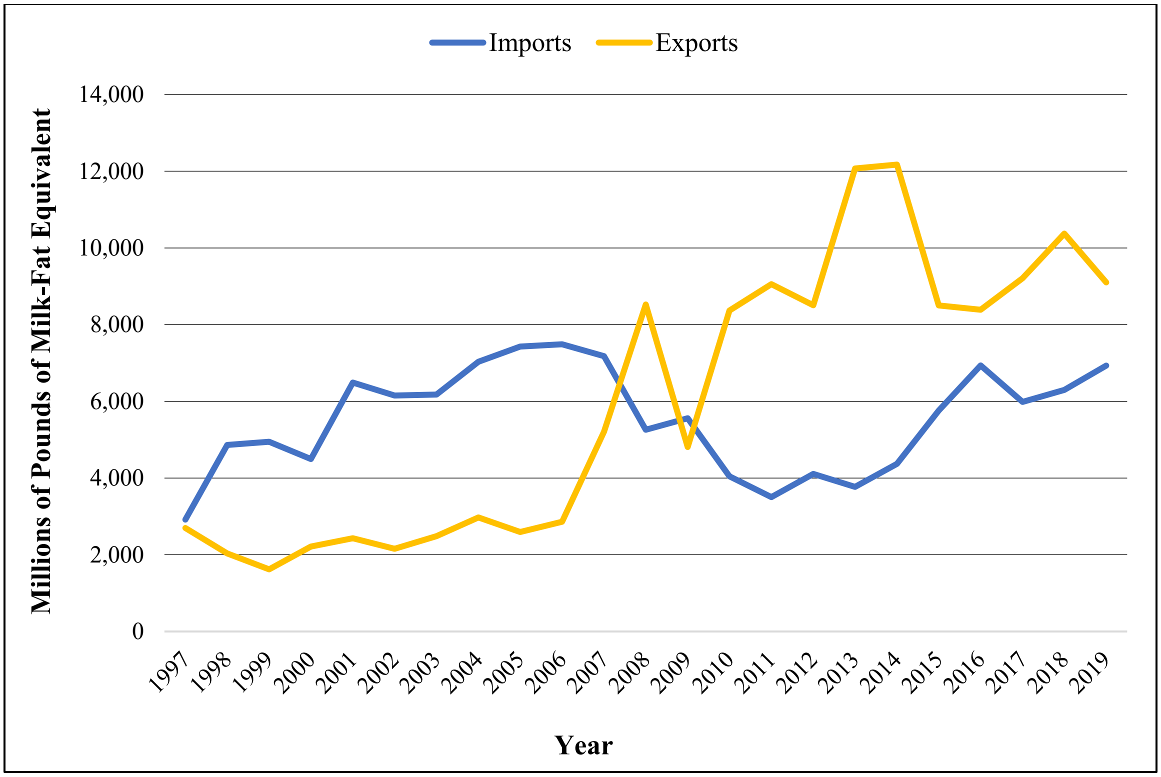

Figure 2.5 – Dairy Exports and Imports from 1997 to 2019 (data from USDA)

Regardless of the size of the operation, the type of cows milked, or the location of the operation, all dairy farms face the same foundational challenges. Cows produce milk each day and as a result, dairy farmers cannot easily or quickly change their level of milk production to respond to market changes and forces. If milk prices fall below the cost of production a farmer cannot "shut off" her cows. If the farmer finds herself in a period of significantly higher prices and wants to grow, it will take some time for her to expand her operation through either purchasing cattle or breeding more cattle for the next season. Dairy farmers also face seasonal changes in milk production per cow. Individual cow productivity is higher in the Spring and lower in the Fall months which results in farmers experiencing fluctuations in revenue throughout the year. In addition, milk itself has a short shelf life compared to other commodities meaning it must be consumed or turned into other products rather quickly.

For several decades, the majority of dairy farmers in the U.S. have been subject to the regulations of the Federal Milk Marketing Order (FMMO) system. The FMMO system establishes a complex pricing system that aims to ensure sustainable prices for producers and a consistent supply of dairy products for consumers; it is important to note that FMMOs regulate dairy processors and not farmers (AMS n.d.). Eleven FMMOs are currently in place and cover about 83 percent of total U.S. milk production (Laine 2016). Figure 2.6 (below) shows which parts of the continental United States are under the FMMO system.

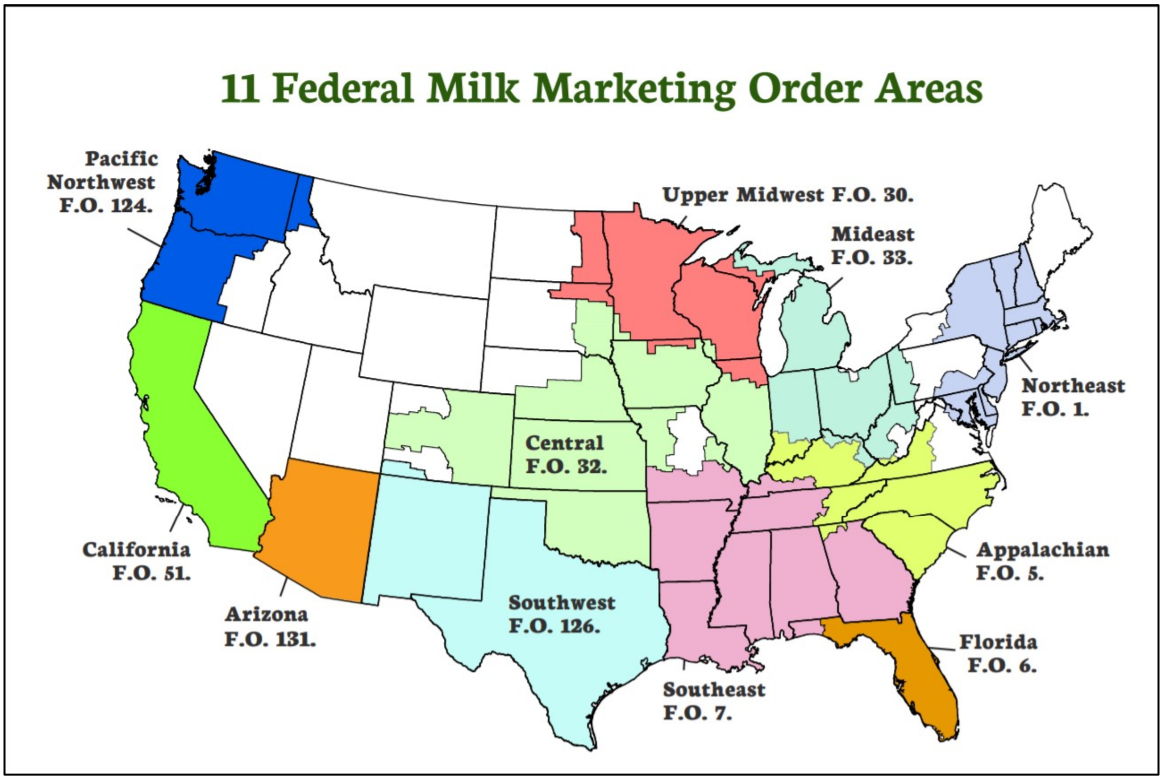

Figure 2.6 – Map of Current Federal Milk Marketing Orders (from USDA)

Under FMMOs, certain provisions are established under which dairy processors buy milk from farmers in a particular marketing area which is defined as a geographic area where processors compete for milk sales (AMS n.d.). Each FMMO includes a classified price plan, a system of minimum prices, and provisions for administering the terms of the order (AMS n.d.).

The past five years are a good representation of the price volatility dairy farmers face, even under the FMMO system. Figure 2.7 (below) displays the monthly average milk price received by U.S. dairy farmers from January 2015 to June 2020. Note that the severe drop experienced in April and May 2020 was likely because of the effects that the Covid-19 pandemic has had on dairy consumption in schools and restaurants.

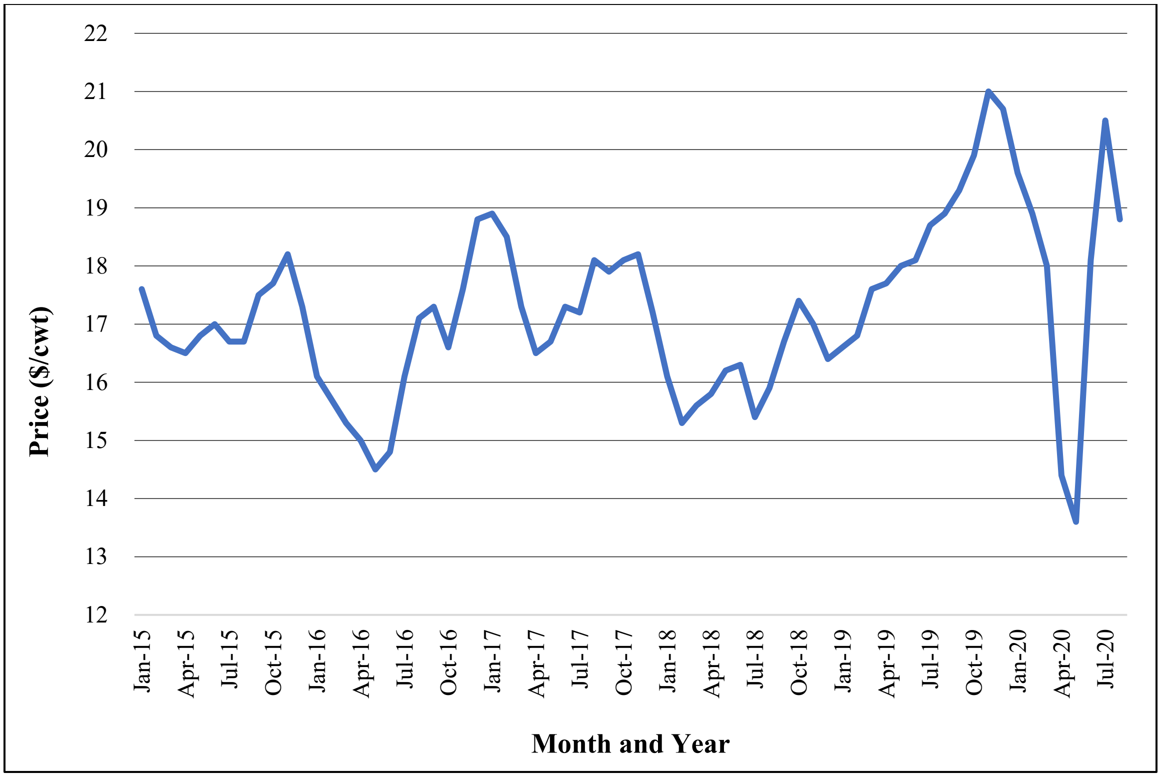

Figure 2.7 – Average Price Received by Dairy Farmers 2015 to 2020 (data from USDA)

Dairy processors have also seen significant changes over the course of the past twenty years. In 2019, 1,266 plants were producing one or more dairy products in the U.S. which is a 13 percent increase from the 1,124 plants there were in 2000 (USDA n.d.). The increase in dairy processors is likely due to the trend of increasing per capita dairy consumption that has been occurring over the past 20 plus years. While per capita consumption of total dairy products has been on a rising trend, the per capita consumption of fluid milk has been steadily decreasing since 1997.

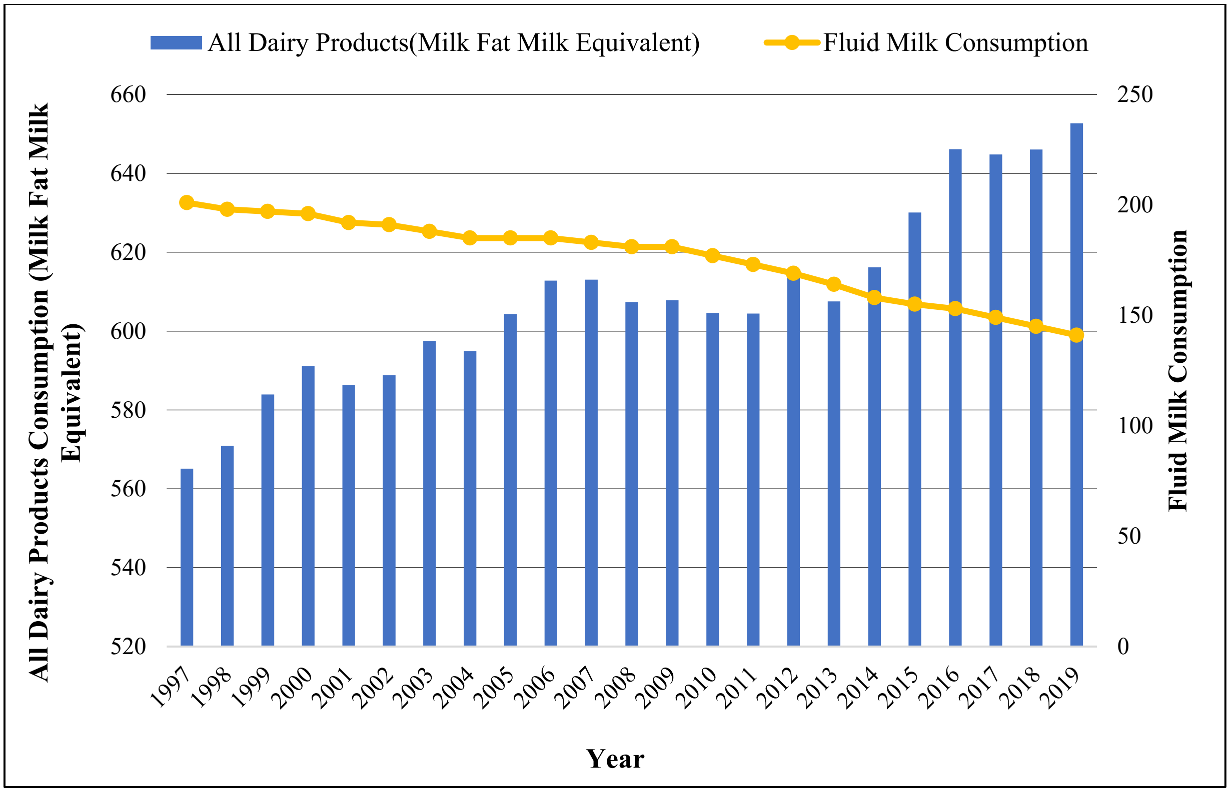

Figure 2.8 – Dairy Consumption (lbs. per capita) from 1997 to 2019 (data from USDA)

Chapter 3 - Dairy Farm Growth

3.1 Motivation

Understanding how different sizes of dairy farms have been growing is critically important to effectively analyze the impact of a growth-based production control on different groups of dairy farms. If a production control policy sets limits on annual growth in milk production, then the farms that are growing the most will be the most impacted. The purpose of this chapter is to determine where dairy farm growth has been occurring over the past twenty years, what the relationship between initial dairy farm size and the rate of dairy farm size growth, and whether smaller dairy farms have been growing more than larger dairy farms or vice versa.

3.2 Previous Work on Dairy Farm Growth

Several previous studies have examined topics related to dairy farm growth. Matulich found significant economies of size to be evident for dairy herds with up to 750 cows (1978). Weersink and Tauer (1991) determined that the major factor affecting dairy farm structure may actually be dairy price policy rather than productivity. In 2001, Wolf and Sumner found that the distribution of dairy farm size was not in fact bimodal as was previously thought, and instead found unimodality to properly characterize the distribution of dairy farm size. Skolrud et al divided dairy farms in Washington state into 10 equally sized cohorts (based on their level of agricultural sales) and looked at their growth; they found the largest three cohorts grew the most during each time period analyzed (2007). In addition, the authors results suggested that the largest cohort of farms may be experiencing diminishing economies of scale but have not yet reached a level that minimizes average cost (Skolrud et al 2007). MacDonald et al determined that the costs of production per cwt of milk fall by nearly half from less than 50 cow herds to 500 cow herds and continues to fall less sharply at larger farm sizes (2007).

3.3 Trends in Dairy Farm Growth Over Past 20 Years

To determine where dairy farms are growing and shrinking and which areas have had the most growth, county-level data is utilized, which is described below.

3.3.1 USDA Ag Census Data Description

The Census of Agriculture is conducted every 5 years and "is a complete count of U.S. farms and ranches and the people who operate them. Even small plots of land - whether rural or urban - growing fruit, vegetables or some food animals count if $1,000 or more of such products were raised and sold, or normally would have been sold, during the Census year" (US Department of Agriculture 2020). Specifically, the Censuses of Agriculture from 1997, 2002, 2007, 2012, and 2017 are utilized.

Specifically, information on the number of operations with milk cows, and the number of milk cows is pulled from each of the census years for each U.S. county for farm size groups of 20-49 head of milk cows, 50-99 milk cows, 100-199 milk cows, 200-499 head of milk cows, and 500 or more milk cows. Farms with fewer than 20 head of cattle are dropped from the dataset because according to the USDA's Economic Research Service (ERS), farms with less than 30 head of milk cows accounted for merely 1.2% of total U.S. milk production in 2006 (MacDonald et al 2007, 3). An average dairy farm size is then calculated for each county without missing information or observations. The data from the 5 censuses being analyzed is then merged together and counties with missing or unreported information in any of the 5 censuses is dropped. The resulting merged dataset contains observations for 700 counties; these counties represented 6.97 million milk cows (74% of U.S. total based on the Milk Production Report) and 32,149 dairy farms (94% of U.S. total) (US Department of Agriculture 2020, 8-18).

3.3.2 Farm Growth Patterns

In this context, dairy farm growth is defined as the change in the county-level average dairy farm size (in number of cows) from 1997 to 2017, in percentage terms. This growth is displayed below in Figure 3.1 (below) where the shades of blue represent counties with a positive growth rate between 1997 and 2017 and the shades of red represent counties with a negative growth rate during the time period.

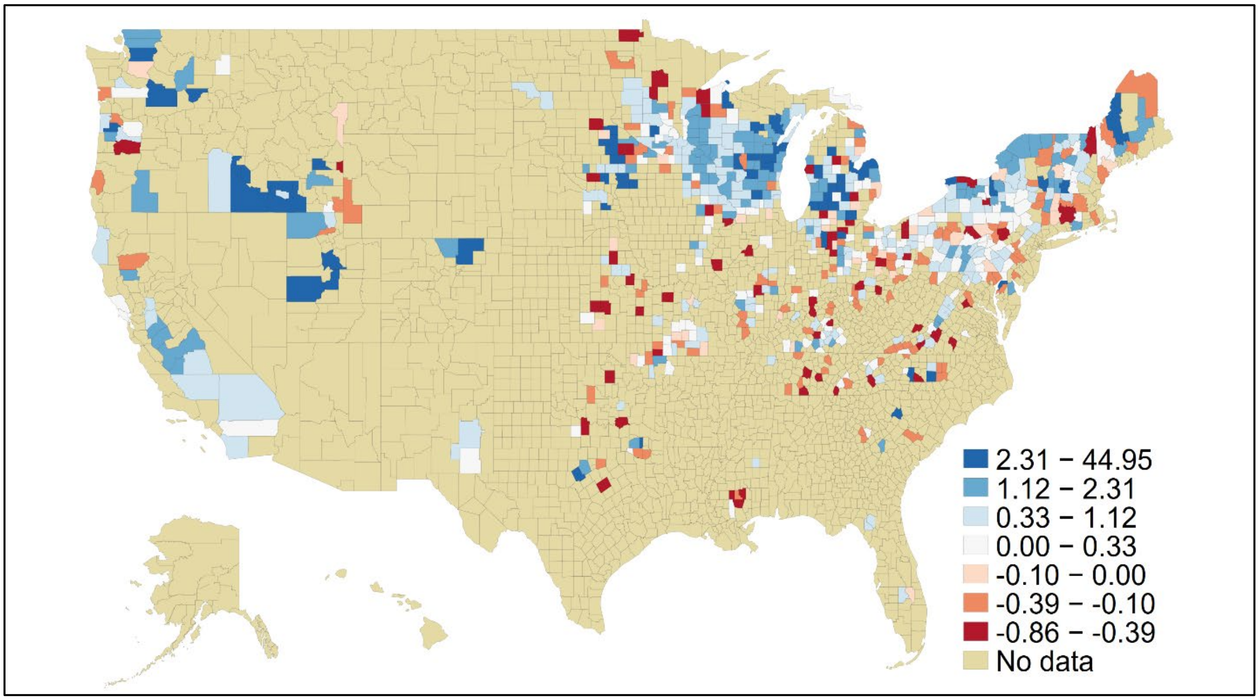

Figure 3.1 – Growth in County Average Dairy Farm Size from 1997 to 2017

Note: the shades of red represent counties with a negative growth rate during the time period and the shades of blue represent counties with a positive growth rate during the time period

As the figure displays, the majority of counties observed in the Western U.S. experienced significant increases in average dairy farm size while farm growth appears much more varied in the Eastern half of the United States. Figure 3.1 (above) also shows that counties in both "traditional" dairy areas such as Wisconsin and Minnesota as well as "contemporary" dairy areas such as Idaho experienced substantial increases in average dairy farm size.

To get a better understanding of where exactly dairy farms are growing, a map is generated displaying counties where the average dairy farm size grew more than three-fold between 1997 and 2017; these counties are shown below in Figure 3.2 where the darker shades of blue represent counties with higher rates of growth.

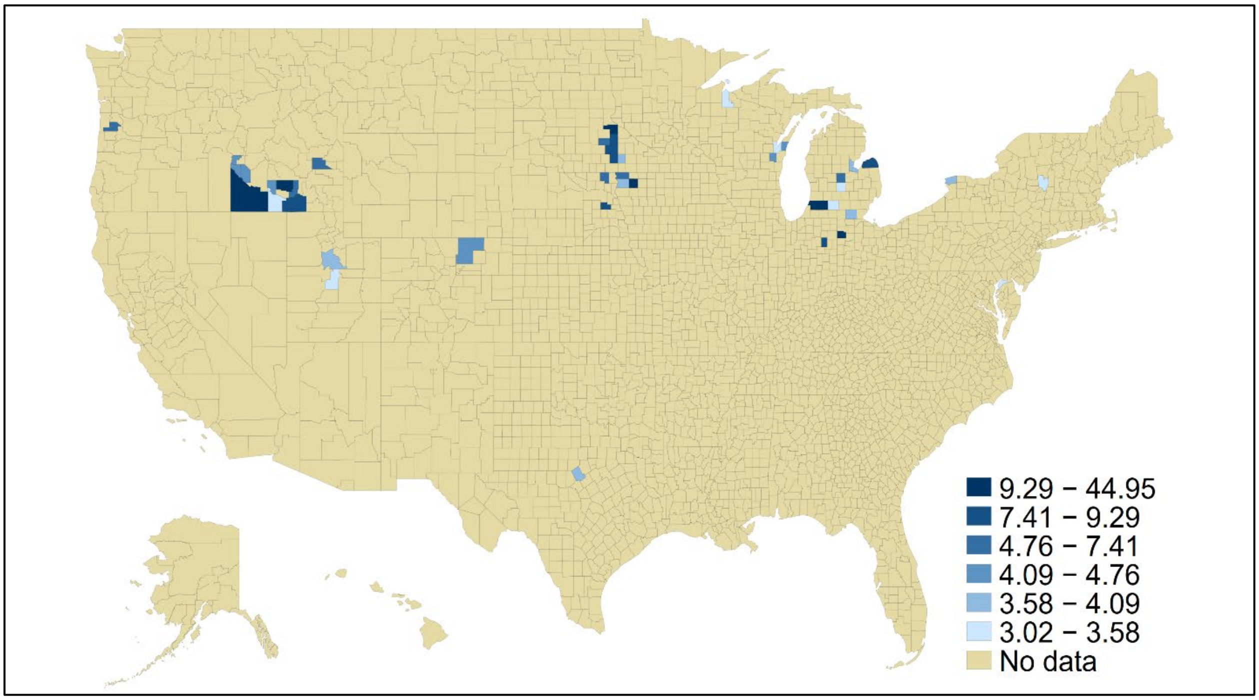

Figure 3.2 – Counties with Fastest Growing Average Dairy Farm Size
Note: the darker shades of blue represent counties with greater rates of growth

As can be seen in the figure, the majority of the counties observed in southern Idaho and eastern South Dakota experienced some of the strongest growth in county average dairy farm size. Interesting to note that the majority of the fastest growing counties are in the western half of the U.S.

Similarly, a map is generated to display counties where the average dairy farm size was negative or shrinking; these counties are displayed below in Figure 3.3 where the *lighter* shades of red represent counties with greater shrinkage in the average dairy farm size.

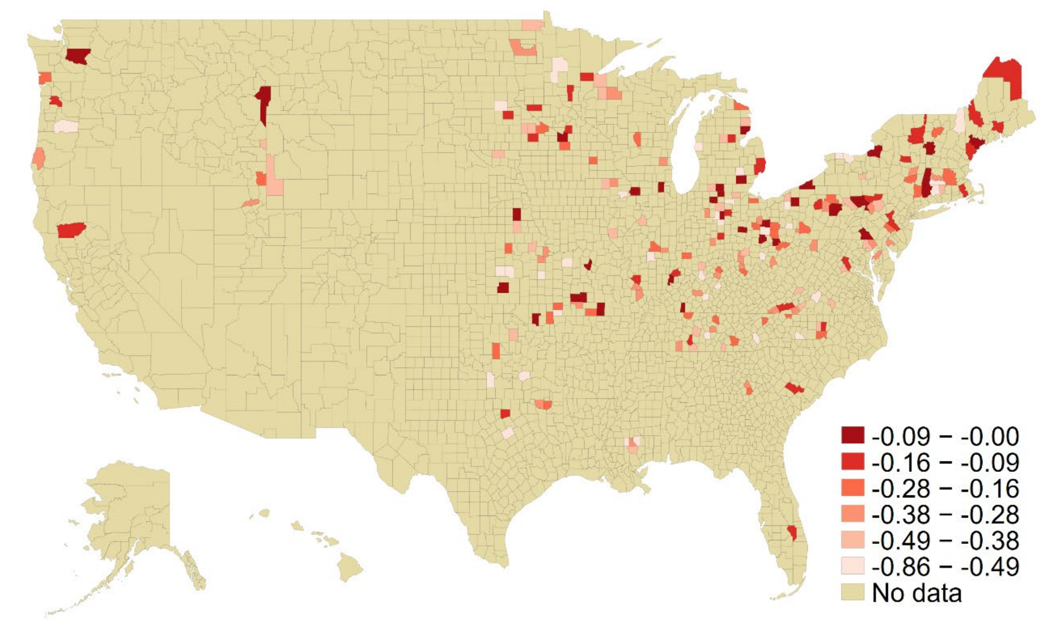

Figure 3.3 – Counties with the Most Negative Average Dairy Farm Size Growth

Note: the lighter shades of red represent counties with greater decreases in farm size

The figure shows that the vast majority of the counties where the average farm size is falling the most are in the eastern half of the United States. There was still some shrinkage in average farm size in the western U.S., just with less frequency than the eastern half of the country.

3.3.3 Relationship between Farm Size and the Rate Farm Growth

In addition to examining patterns and trends in county-level dairy farm growth, an attempt is made to quantify the relationship between a county's initial average dairy farm size and the rate of growth experienced by that county from 1997 to 2019.

The same USDA Ag Census data is utilized. Regressions are run to determine how initial farm size in 1997 affects the growth rate experienced between 1997 and 2017 for all 700 counties in the data set. Equation 3.1 (below) illustrates the anatomy of the regressions ran.

$$log Growth\ Rate\ from\ 1997\ to\ 2017 = \alpha + (\beta \times log 1997\ farm\ size) \qquad (3.1)$$

The regressions are run for several different groups. First, the regression is run for all 700 counties and the results are displayed below in Table 3.1. There is a positive relationship between a county's initial average farm size in 1997 and the growth rate of the average farm size in that county between 1997 and 2017. As the initial farm size increases by 1 percent, the growth rate for that county increases 0.19 percent.

Table 3.1 – Regression Results for All Counties

	(1) logLHS9717
logI97	0.190^{***}
	(0.0434)
_cons	-0.488^{*}
	(0.190)
N	700
R^2	0.027

Standard errors in parentheses
$^{*}\ p < 0.05$, $^{**}\ p < 0.01$, $^{***}\ p < 0.001$

The same regression is then run again, but this time for two different groups. For all counties in the dataset that are in an FMMO and all counties in the dataset that are not in an FMMO; the results of these regressions are displayed below in Table 3.2. For both groups, a statistically significant and positive relationship was found to exist between a county's initial average farm size in 1997 and their growth rate. The relationship was significantly more positive for counties that are not in an FMMO as a 1 percent increase in average farm size results in a 0.71 percent.

Table 3.2 – Regression Results for Counties in an FMMO and Counties not in an FMMO

	FMMO Counties	Non-FMMO Counties
’97 Farm Size	0.102^{*}	0.706^{***}
	(0.0471)	(0.100)
Intercept	-0.110	-2.728^{***}
	(0.207)	(0.443)
N	577	123
R^2	0.008	0.291

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

The same regression is again run, but this time for each of the FMMOs (besides Arizona due to a lack of observations in that FMMO); the results of these 10 regressions are displayed below in Table 3.3. Statistically significant relationships were found to exist between initial county average farm size and the growth rate for some of the FMMOs. All but one of these statistically significant relationships were positive. By far the strongest relationship was in the Upper Midwest FMMO which includes primarily Minnesota and Wisconsin, an area where farm numbers have been falling substantially in recent years, where a 1 percent increase in the initial county average farm size increases the growth rate for that county by 1.4 percent. In the Southeast FMMO, increasing the initial size by 1 percent decreases the growth rate by 0.6 %. This suggests that in places such as the Upper Midwest FMMO large farms are growing faster while in the Southeast FMMO smaller farms are growing faster than large farms.

Table 3.3 – Regression Results for Each Federal Milk Marketing Order (FMMO)

	N.E. Order	A.P. Order	FL Order	S.E. Order	U.M. Order	CA Order	C.L. Order	M.E. Order	P.N.W. Order	S.W. Order
'97 Farm Size	0.463^{*}	0.159	-0.322	-0.644^{**}	1.366^{***}	0.136	0.152	0.679^{**}	0.571^{*}	0.205
	(0.230)	(0.233)	(0.085)	(0.225)	(0.267)	(0.121)	(0.233)	(0.211)	(0.217)	(0.277)
Intercept	-1.717	-0.698	2.562^{*}	2.715^{**}	-4.973^{***}	-0.291	-0.261	-2.499^{**}	-2.553^{*}	-0.983
	(1.001)	(1.014)	(0.564)	(0.978)	(1.088)	(0.763)	(0.966)	(0.876)	(1.182)	(1.591)
N	85	44	4	44	128	16	87	135	20	13
R^2	0.046	0.011	0.878	0.163	0.172	0.082	0.005	0.072	0.278	0.047

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

N.E. = Northeast; A.P. = Appalachian; FL = Florida; S.E. = Southeast; U.M. = Upper Midwest; CA = California; C.L. = Central; M.E. = Mideast;
P.N.W. = Pacific Northwest; S.W. = Southwest

Figure 3.4 (below) illustrates all of the FMMOs with statistically significant relationships between initial county average farm size and the county growth rate between 1997 and 2017.

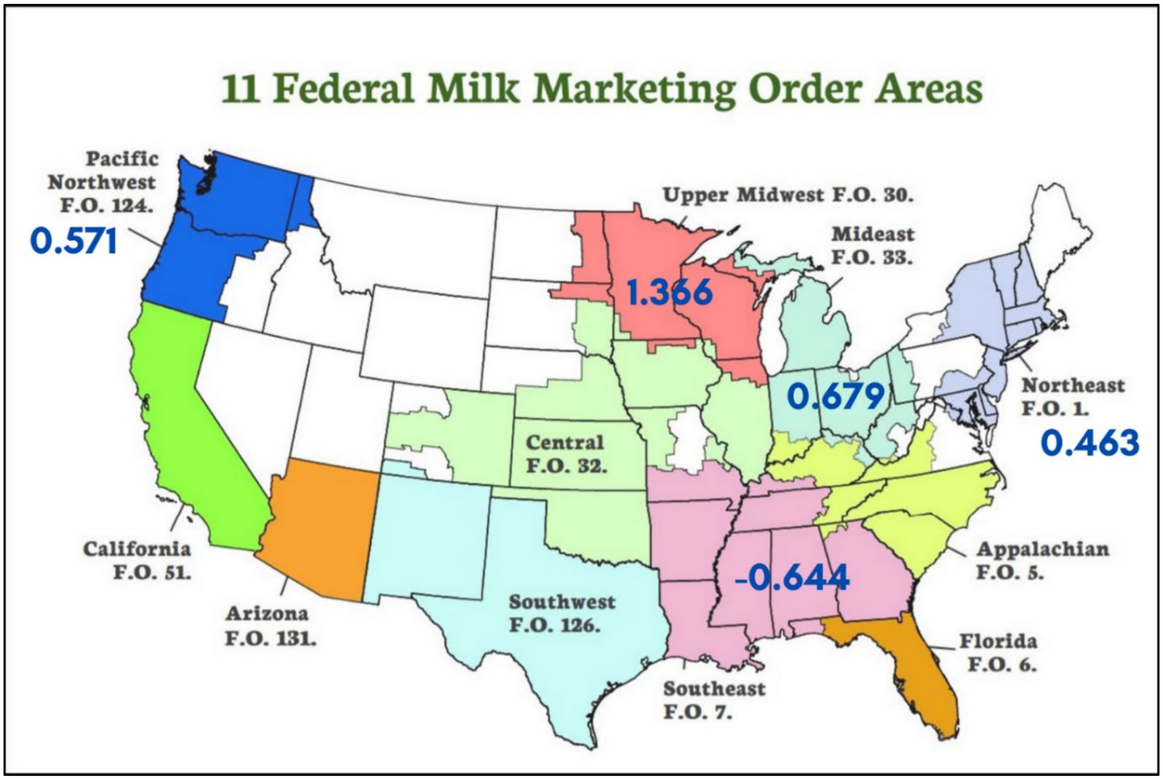

Figure 3.4 – Map of FMMOs with Statistically Significant Relationships

The same regression is then run one additional time, this time for each of the USDA's Dairy Product Regions (DPRs). Figure 3.5 (below) visualizes the states under each of the DPRs.

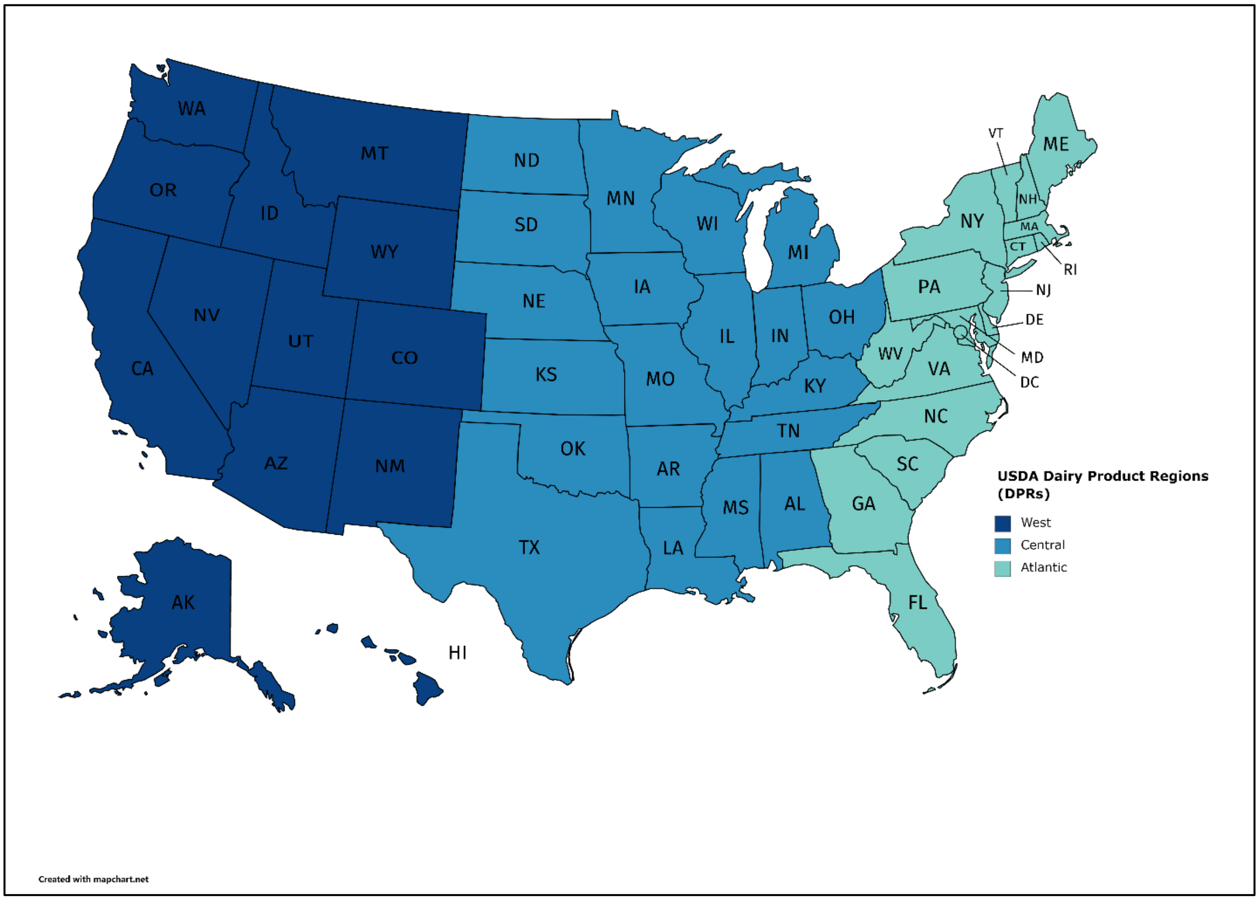

Figure 3.5 – Map of USDA Dairy Product Regions (DPRs)

The results of the regressions for each of the DPRs are shown below in Table 3.4. As the table illustrates, none of the DPRs had a statistically significant relationship between farm size and growth.

Table 3.4 – Regression Results for Each USDA Dairy Product Region (DPR)

	West DPR	Central DPR	Atlantic DPR
’97 Farm Size	0.0843	0.0805	0.152
	(0.114)	(0.105)	(0.0779)
Intercept	0.285	0.000345	-0.451
	(0.643)	(0.437)	(0.343)
N	62	432	204
R^2	0.009	0.001	0.019

Standard errors in parentheses
$^{*}\ p < 0.05$, $^{**}\ p < 0.01$, $^{***}\ p < 0.001$

3.3.4 Summary of Dairy Farm Growth Trends Over the Past 20 Years

Growth in the county-level average dairy farm size between 1997 and 2017 tended to be positive in the Western half of the United States while it was more varied between positive and negative in the Eastern half of the United States according to data from the USDA’s Ag Census. The counties with the most shrinking average farm size tended to be in the Eastern half of the U.S. while the most growing counties were concentrated primarily in the Western half of the United States.

The results of attempting to quantify the relationship between a county’s initial average farm size and that county’s growth between 1997 and 2017 are mixed. When looking across all 700 counties pulled from the USDA Ag Census from 1997 to 2017, there is a statistically significant and positive relationship between initial farm size and a county’s growth rate. A positive relationship between initial farm size and the growth rate means that the larger a farm is to begin with, the greater their growth rate which suggests larger dairy farms are growing more than smaller dairy farms. When comparing the 577 counties of the dataset that are in an FMMO to the 123 that are not, the counties not in an FMMO show a much stronger, positive, and statistically significant relationship between initial farm size and growth in average farm size. When looking at each FMMO (besides Arizona due to a lack of observations), all but one of the orders with a statistically significant relationship had a positive relationship between initial farm size and the growth rate. The Upper Midwest FMMO, in particular, stands out as a 1% increase in the initial county average farm size in this order increases the growth rate by more than 1%. When looking at each of the three USDA Dairy Product Regions, there was no statistically significant relationship found between a county's initial average farm size and the growth rate, but all the relationships found were positive.

3.4 Annual Dairy Farm Growth by Farm Size and DPR

3.4.1 USDA Agricultural Resource Management Survey Data Description

A special tabulation from the USDA's Agricultural Resource Management Survey (ARMS) is also utilized to analyze annual dairy farm growth over time.

"Agricultural Resource Management Survey (ARMS) is the U.S. Department of Agriculture's primary source of information on the production practices, resource use, and economic well-being of America's farms and ranches. The results of this survey are the only source of information available for objective evaluation of many critical issues related to agriculture and the rural economy. Farmer participation in ARMS ensures that policymakers and others, including farmers and ranchers themselves, base important decisions on facts straight from the source. ARMS also tells the story of American agriculture to the public that has less and less direct contact with the farm community" (USDA 2020).

In the special tabulation, percent change in farms herd size aggregated over the same farm size groups as used in the Ag Census data and across each of the Dairy Product Regions. Percentiles are also provided for the percent herd change for each size group and region for the 10, 25, 50, 75, 90 percentiles. A very sincere thanks is owed to James MacDonald at the USDA's

Economic Research Service (ERS) for providing the special tabulation for the 2000 and 2016 ARMS years.

3.4.2 Distribution of U.S. Dairy Farms by Size in 2000 and 2016

The distribution of dairy farms by size group has changed significantly between 2000 and 2016. As Figure 3.6 (below) illustrates, the total number of dairy farms has dropped significantly over the past two decades.

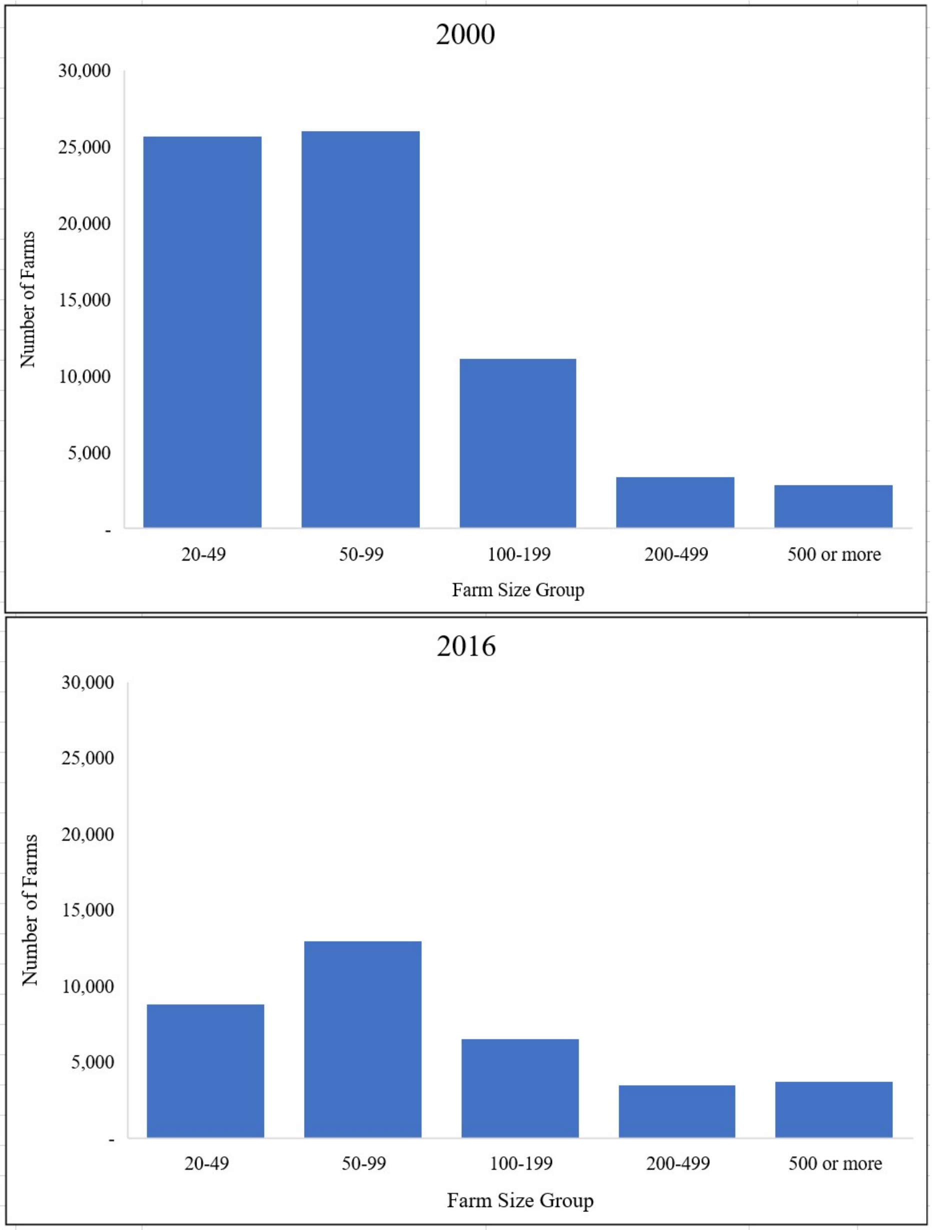

Figure 3.6 – Distribution of Dairy Farms by Size in 2000 and 2016

The number of farms in the 500 or more head size group actually grew noticeably between 2000 and 2016. The 50-99 head size group remained the farm size group with the highest number of farms in both years. The distribution also changed to being less left-skewed between 2000 and 2016.

3.4.3 Patterns of Dairy Farm Growth by Initial Farm Size in 2000 and 2016

In the special tabulation, farm growth was calculated as the change in the milk cow inventory at the beginning and end of the year, so farm growth is an annual change in this context and is calculated for both 2000 and 2016. Figure 3.7 (below) visualizes the percent change in herd size by farm size group and percentile of farm growth in both 2000 and 2016 for the Western DPR.

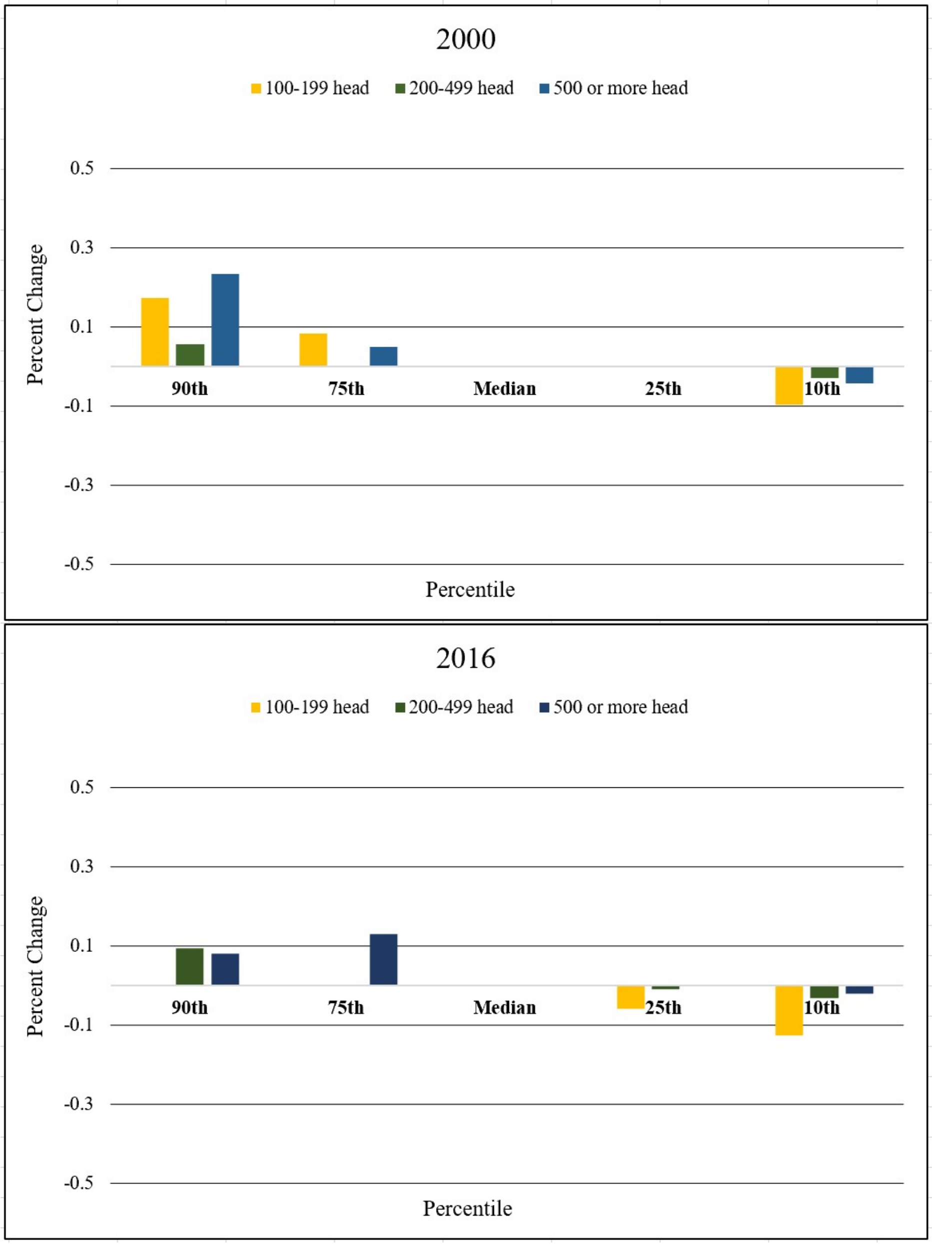

Figure 3.7 – Growth in Farm Size in the West DPR in 2000 and 2016

As can be seen in the figure above, in 2016 there were more negative percent changes in herd size compared to 2000.

Figure 3.8 (below) visualizes the percent change in herd size by farm size group in both 2000 and 2016 for the Central DPR.

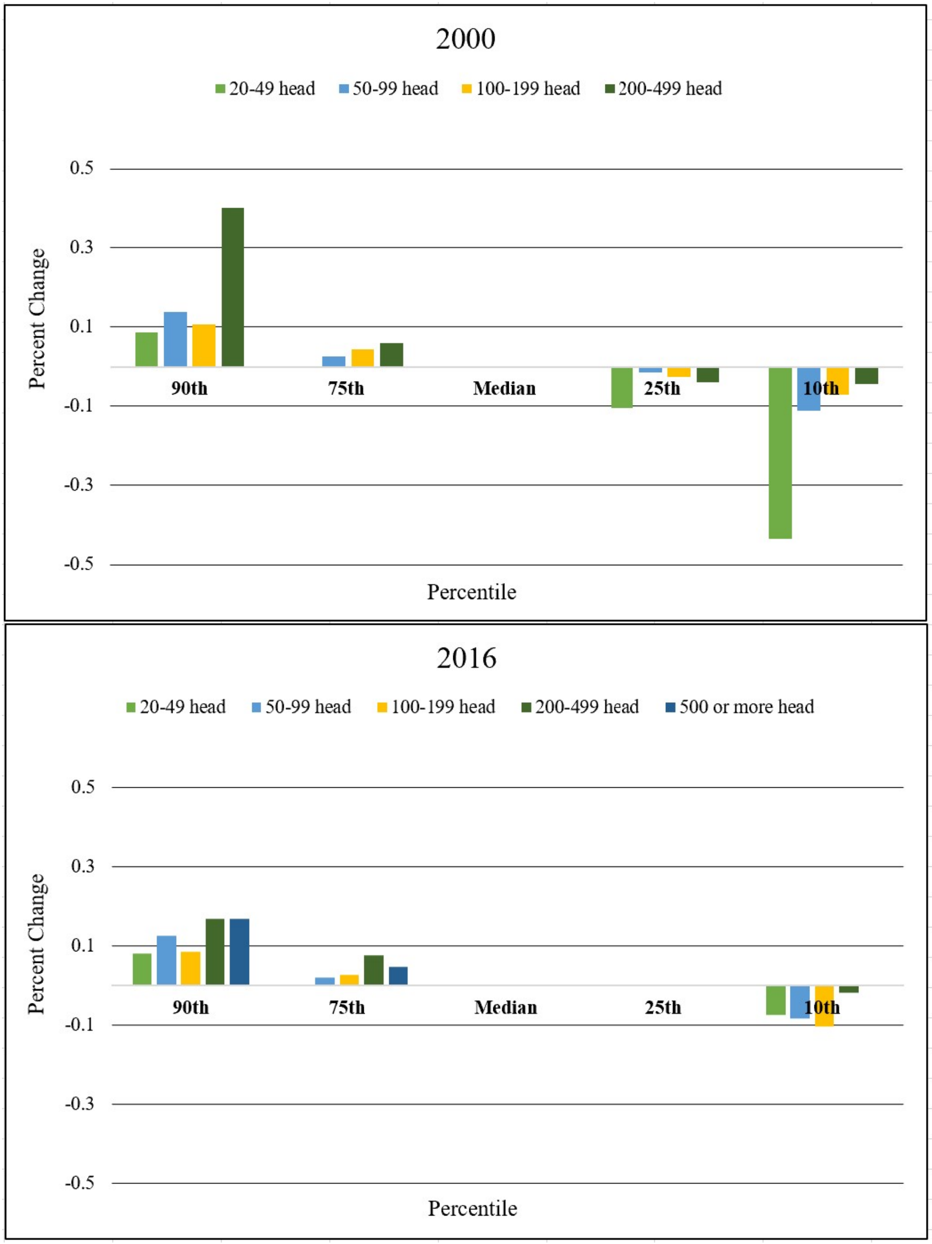

Figure 3.8 – Growth in Farm Size in the Central DPR in 2000 and 2016

As can be seen in the above figure, there were fewer negative percent changes in herd size for all farm sizes in 2016 compared to 2000. There also seemed to be more growth in herd size in 2016, particularly in the 75th percentile.

Figure 2.9 (below) visualizes the percent change in herd size by farm size group in both 2000 and 2016 for the Atlantic DPR.

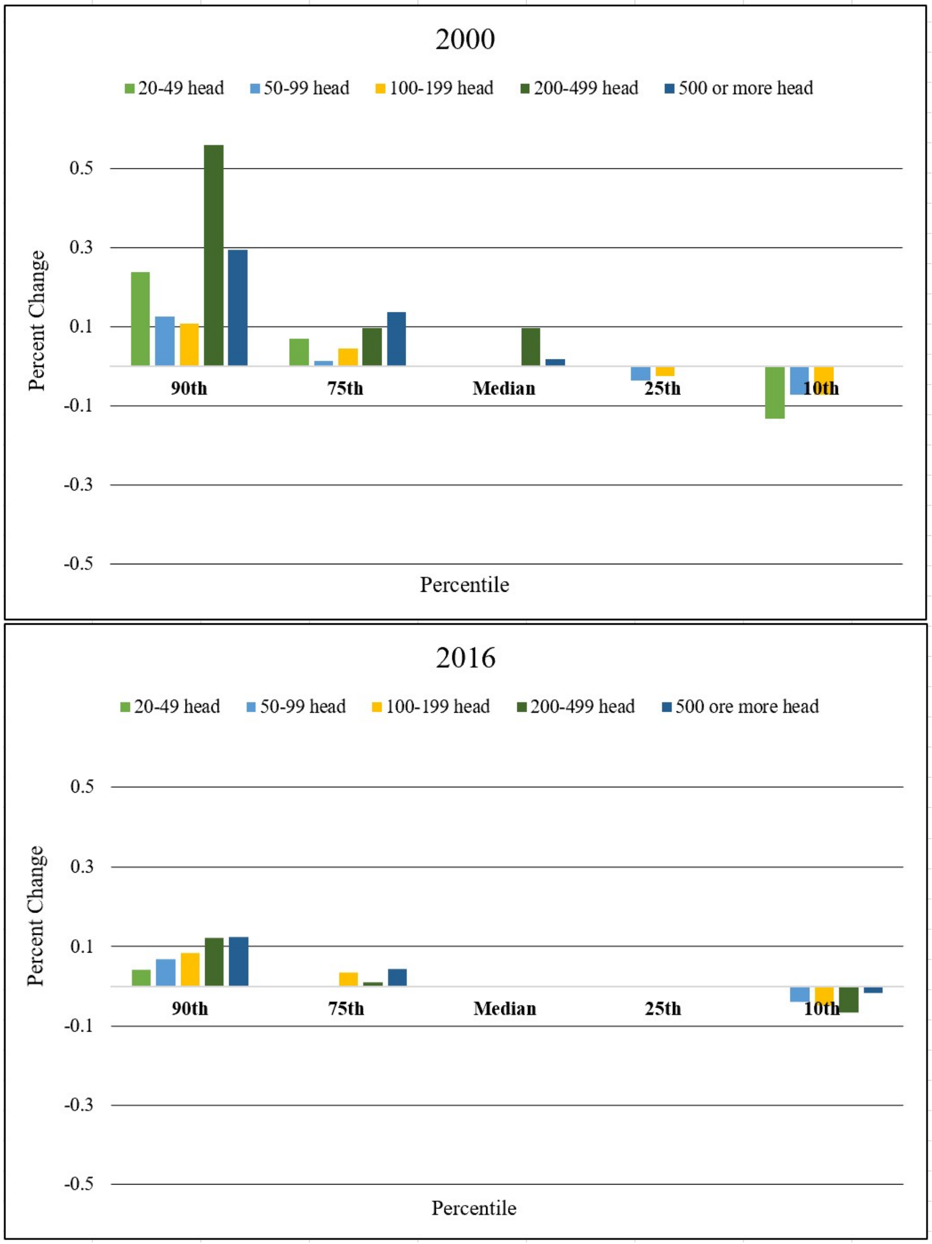

Figure 3.9 – Growth in Farm Size in the Atlantic DPR in 2000 and 2016

As can be seen in the above figure, growth in the 90th percentile was weaker but more uniform in 2016 compared to 2000. The negative percent herd size changes in the 10th percentile were also weaker in 2016 compared to 2000.

3.4.4 Summary of Annual Dairy Farm Growth

In 2000, the greatest growth across all farm sizes seemed to be occurring in the Atlantic DPR while in 2016 the most growth appeared to be taking place in the Central part of the U.S. In the largest farm size category, it appears that the Atlantic and Central DPRs were growing more than the Western part of the U.S. Shrinkage in the smallest size category of dairy farms decreased significantly in the Central DPR between 2000 and 2016.

To get a better idea of whether larger farms are growing more than smaller farms or vice versa, mean growth rates are calculated for all five farm size groups in both 2000 and 2016; these rates are displayed below in Table 3.5.

Table 3.5 – Summary of Annual Growth Farm Rates

Farm Size Group	Annual Growth Rate in 2000 (%)	Annual Growth Rate in 2016 (%)	Change from 2000 to 2016
20-49 milk cows	-13.9	0.9	+14.8%
50-99 milk cows	-2.6	0.5	+3.1%
100-199 milk cows	2.2	0.2	-2%
200-499 milk cows	3.4	3.8	+0.4%
500 or more milk cows	5.6	1.4	-4.2%

Note: the above results are based on the special tabulation from the ARMS Survey that represents 36,360 dairy farms in 2016 and 71,332 dairy farms in 2000

As can be seen in the table above, in both 2000 and 2016, the two largest farm size groups were growing at a greater rate than the three smallest farm size groups. In 2016 however, the difference in growth rates between the largest farm size group and the smallest farm size group was significantly less as the rate of growth of the smallest farm size group increased nearly fifteen percent. In 2016 all farm size groups were growing at a positive rate which is a big jump from 2000 when the two smallest farm size groups were actually shrinking in terms of farm size. Simply put, large farms have been growing more than smaller farms, although the growth rate of smaller farms has been increasing more for smaller farms than for larger farms.

Chapter 4 - Welfare Impacts of a Growth-Based Production Control on Dairy Size Groups

4.1 Impacts of Previous Production Controls in the U.S. Dairy Sector

Production controls are not an entirely new concept to the U.S. dairy sector, with multiple Federal programs utilized in the 1980s. In 1983, Congress created the Milk Diversion Program (MDP) where producers were paid to reduce their milk production between 5 and 30 percent of their base levels and this program was in effect for 15 months (Newton 2019). According to Newton, surveys from the Government Accountability Office (GAO) found that the "likely program participants had already reduced milk production below their base levels. Nonparticipants were those dairy farmers who were actively expanding sales" (2019). Bruce, Susanto, and Berry found that the MDP had a short-term impact with production recovering half of the reduction induced by the program within just 1 year (1991).

The 1985 Farm Bill included a Milk Termination Program (MTP) where farmers were paid to terminate their milk production and to stay out of dairying for at least 5 years and this program was in place for 18 months from April 1986 onward (Newton 2019). Again, this program had little impact on national production since nonparticipating farms increased their production during the 18-month period (Newton 2019). Bruce, Susanto, and Berry found that the rate of recovery of production to pre-program levels was slower for the MTP than the MDP suggesting a longer-term impact of the MTP (1991). However, they found herd size began increasing immediately to pre-program levels after the last month of the MTP which suggests the 5-year ban on entering dairying for participating producers had little impact (Bruce et al 1991).

After the Federal production control programs, a voluntary production control program was formed by dairy farmer cooperatives. In this program, farmers were paid to either reduce their milk production or to take their entire cow herd out of production (Newton 2019). According to Newton (2019), “over the 7-year life of the program, the herd buyout program is estimated to have removed 510,000 milking cows from production”. For some context, this would have represented around 5 and a half percent of the U.S. milk cow herd in 2019 (USDA 2020).

4.2 Present Debate on Production Controls for the U.S. Dairy Sector

As explained earlier in the introduction, overproduction has been a consistent problem for the U.S. dairy sector. A large reason for this is that adjusting to market signals is difficult for dairy farmers even in the best circumstances. Dairy cows produce milk each day so when prices rise (or fall) farmers cannot immediately ramp up (or cut back) production; it takes significant time to react. Farmers have an incentive to produce as much milk as they profitably can so when prices rise significantly, farmers will add more cows (through purchasing or breeding) to expand their production. Over time when the price decreases again, farmers cannot reduce production right away since they have expanded their herd; as a result, price increases often lead to long periods of excess supply. Several years of excess supply and even the demand disruptions from the Coronavirus pandemic have ignited conversations among dairy farmers and industry groups about production controls for the industry.

The position of industry groups on production controls varies across groups and has changed over time. In an article from Wisconsin Public Radio, Mark Stephenson, the Director of Dairy Policy Analysis at the University of Wisconsin-Madison, stated “Many dairy industry groups have traditionally been against efforts to control the supply of milk as a way to keep prices at a profitable level … ‘There is no option right now except to reduce milk production. We can’t do this with simply lower market prices’” (Kirwan 2020). Stephenson went on to say, “the dairy industry needs a way to entice all farms to produce less, or painfully low prices will force farms out of business all together" (Kirwan 2020). This highlights the important role production controls could play in the industry and the impact they could have on all farms.

Producer groups may see a need for production controls for the dairy sector, but they have differing ideas and opinions on what they should look like. In 2019, Farm Bureau "decided to oppose a mandatory quota system with the willingness to consider a flexible supply management system that is administered through the marketplace and not through the Federal government" (Farm Bureau 2019). On the other hand, groups such as the Wisconsin Farmers Union, the National Farmers Union, and the California Dairy Campaign are more supportive of a production control system that involves some degree of government intervention in the marketplace (Wagoner 2020). Industry groups are not the only ones divided on the issue of production controls for the dairy sector.

Individual dairy farmers are also divided on dairy production controls. Farmers are paid for each unit of milk they produce so they have an economic incentive to produce as much milk as they profitably can, so some farmers do not want to sacrifice their ability to make individual decisions based on this incentive. Some farmers are opposed in principle to any sort of production control as they are strong proponents of the free market. Some farmers are opposed to production controls as they believe they limit the ability for operations to grow.

Different proposals for production controls have been made by different dairy industry groups. In 2019, the Wisconsin Farmers Union commissioned a report on two different production control plans; one plan where farmers are paid a low price on milk produced above an allowable amount (similar to the Dairy Market Stabilization Program initially proposed by the National Milk Producers' Federation) and a second plan where production is allowed to grow a specified amount each year and if a farmer exceeds the allowable growth they are assessed market access fees (which differ by farm size) (this plan is similar to the Growth Management Program promoted by the Milk Producers' Council in 2009) (Charles and Stephenson 2019, 4-5). The growth management plan is the one that came out more favorably from dairy farmers (Wagoner 2020). Since a growth-based production control is the type of plan that had the most support among producers, that is the type of production control that will be analyzed here. Important to note that the report commissioned by the Wisconsin Farmers Union analyzed the impact of the growth management plan on milk prices, net farm income, and overall production while this analysis that follows focuses on the welfare impacts of a growth-based production quota with a range of scenarios.

4.3 A Graphical Model of Growth-Based Supply Control

Before walking through the numeric set-up of the EDM and the subsequent simulations utilizing the model, it is important to understand the EDM in a supply and demand graphical space. In this model, a few assumptions are imposed including that the only product produced in the U.S. dairy sector is fluid milk, and that a national growth-based production quota (hereafter referred to as "the quota") is imposed on the industry, allowing milk production to grow up to a specified percentage annually from some base level. To simplify the visual illustration of the model, the graphical representation assumes that milk is produced by only two groups of dairy farms, big farms (B) and small farms (L) while the numeric representation breaks down total market milk production by five size groups (20-49 head, 50-99 head, 100-199 head, 200-499 head, and 500 or more head). Figure 4.1 (below) displays this simplistic representation of the U.S. dairy sector.

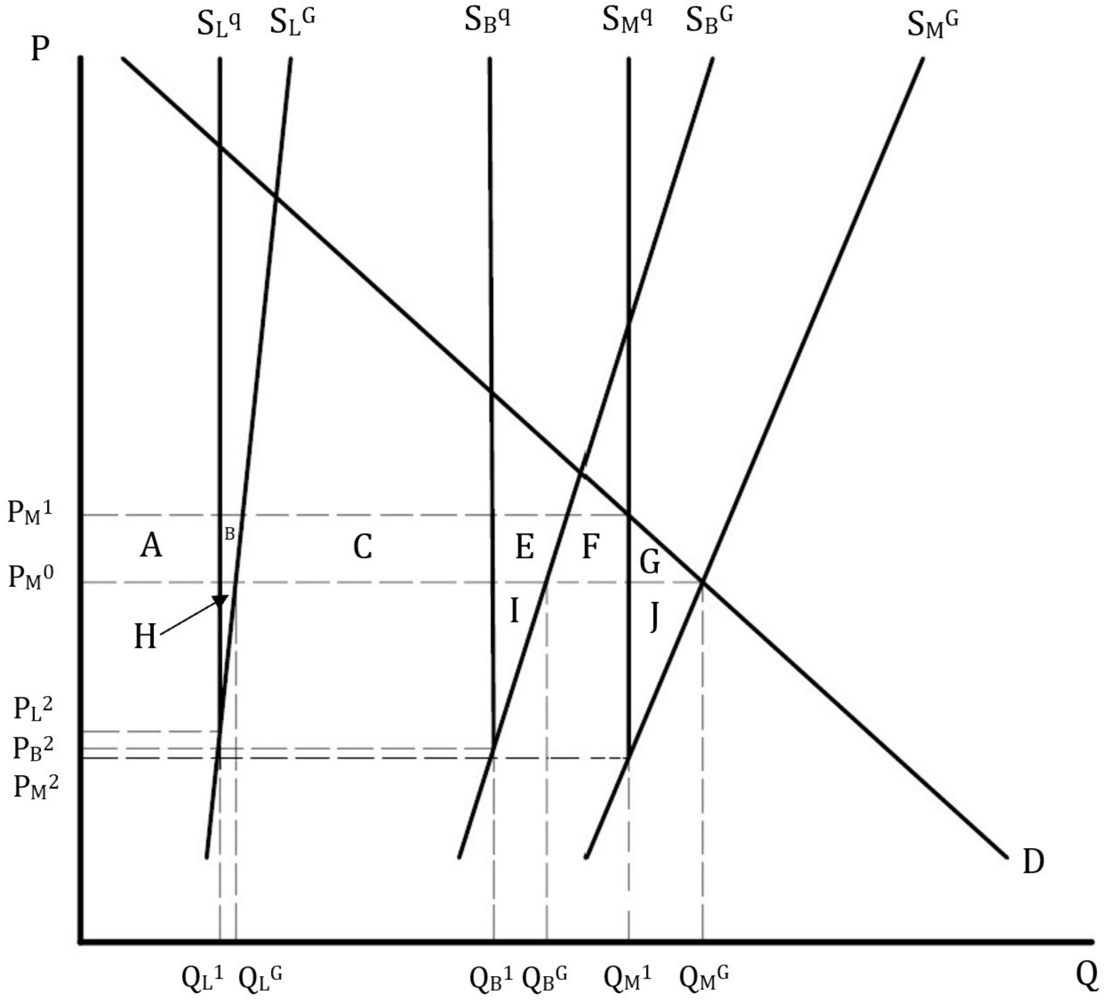

Figure 4.1 – U.S. Dairy Sector Under a Growth-Based Production Quota

The explanation of the graphical representation of the model is split into three sections: the total market, big farms, small farms. Note that all references to curves, prices, and quantities in these three sections are referring to Figure 4.1 (above). Also note that, in the graphical representation of the model, it was assumed that big farms are growing faster than smaller farms based on the work done in Chapter 3.

4.3.1 The Total Market

The line labeled S_M^G represents the total milk supply for the market under normal conditions (without the quota). In other words, S_M^G shows the total quantity of milk U.S. dairy farmers would produce at each price point without the quota in place. The market demand curve is shown by the line labeled D and depicts the quantity of milk demanded by consumers at each price point. Market equilibrium price and quantity of milk without the growth-based production quota in place is shown at P_M^0 and Q_M^G, respectively.

Under the quota, the market supply curve (S_M^G) kinks and goes vertical at the quantity where the maximum allowed increase in production is reached (Q_M^1). The new market supply curve is represented by S_M^q. Since the quota affects only milk production, the market demand curve is unchanged. The new market equilibrium price and quantity exist where the new market supply curve (S_M^q) intersects the market demand curve (D) which is shown at P_M^1 and Q_M^1, respectively.

4.3.2 Big Farms

The line labeled S_B^G represents the milk supply of big farms under normal conditions (without the quota). In other words, S_B^G shows the quantity of milk big dairy farms would produce at each price point without the quota in place.

Under the quota, the big farms' supply curve (S_B^G) kinks and goes vertical at the maximum quantity of production they can reach under the policy (Q_B^1). P_B^2 is the price point where the big farms' supply curve (S_B^G) kinks to being vertical. The new supply curve for big farms is represented by S_B^q.

4.3.3 Small Farms

The line labeled S_L^G represents the milk supply of small farms under normal conditions (without the quota). In other words, S_L^G shows the quantity of milk small dairy farms would produce at each price point without the quota in place. Note that the letter L is used to signify "little" or small farms since S is already used to denote supply.

Under the quota, the small farms' supply curve (S_L^G) kinks and goes vertical at the maximum quantity of production they can reach under the policy (Q_L^1). P_L^2 is the price point where the small farms' supply curve (S_L^G) kinks to being vertical. The new supply curve for small farms is represented by S_L^q.

4.3.4 Producer and Consumer Welfare Measures

To calculate the impact of the quota on different groups in the U.S. dairy sector, producer and consumer welfare measures are used. Specifically, the model employs change in producer surplus (ΔPS), change in consumer surplus (ΔCS), and change in social welfare (ΔSW). Each of these measures is explained and shown graphically through Figure 3.1 (above).

To determine the impact of the quota on small farms, large farms, and farms as a whole, ΔPS is utilized. Producer surplus (PS) measures the revenue in excess of what dairy farmers are willing to accept to produce their milk.

Graphically, total market producer surplus without the quota in place is represented by the area above the market supply curve (S_M^G) and below the market equilibrium price without the quota in place (P_M^0). Under the quota, all farms receive the higher equilibrium price of P_M^1 which is beneficial, but since the market supply curve is now kinked vertically, farms lose some of the surplus they had without the quota in place. In terms of specific areas of the graph, farms as a whole gain areas $A+B+C+E+F$ and lose area J. This change in welfare can be disaggregated to the different farm size groups.

With their new supply curve under the quota (S_B^q) and the new market equilibrium price (P_M^1), big farms gain areas $A+B+C$ and lose area I. With the new supply curve for small farms under the quota (S_S^q) and the new market equilibrium price (P_M^1), small farms gain area A and lose area H. Note that $I+H=J$ and $A=E+F$.

An important aspect to consider is farmers are not guaranteed to benefit under the quota. In fact, one farm size group could benefit from the quota while another farm size group is negatively impacted. Note that $A+B+C>A$, but $I>J$.

To see the impact of growth-based production quota on consumers, ΔCS is utilized. Consumer surplus (CS) measures the difference between consumers' maximum willingness to pay for milk and the price for the milk that consumers pay. Graphically, consumer surplus without the quota is defined as the area below (or to the left of) the demand curve (D) and above the equilibrium price level (P_M^0). Under the quota and the new market equilibrium price (P_M^1), consumers pay the higher price of P_M^1 and so they lose the areas of $A+B+C+E+F+G$.

To see the net impact of the quota on the entire market, we simply add together the ΔPS and the ΔCS (also known as the change in social welfare (ΔSW)). The net effect is that the market loses the welfare of area J and area G.

The welfare impacts of the quota are summarized in Table 4.1 (below).

Table 4.1 – Social Welfare Impacts Under Growth-Based Production Quota, Summary

	Total Market	Big Farms	Small Farms
ΔCS	-(A+B+C+E+F+G)	N/A	N/A
ΔPS	+(A+B+C+E+F) – J	+(A+B+C) – I	+A – H
ΔSW	-(~~A+B+C+E+F~~+G)	N/A	N/A

+(~~A+B+C+E+F~~) – J
= – (G+J)

4.4 Numerical Model Set-Up

4.4.1 Model Derivation

To calculate the impact of the growth-based production quota on the total milk market, consumers, and different groups of producers, a set of equations must first be derived to calculate the changes in welfare for each of these constituencies. The first step in this derivation process is to establish a set of equations that define the market supply, the market demand, and the condition under which the market will clear. Total market supply under the quota can be represented by the equation

$$Q^S = Q_M^G(1 - \gamma_M) \tag{4.1}$$

where:

Q^S = market supply,

Q_M^G = total market supply of milk under unrestricted production growth (no quota),

γ_M = reduction in total market milk production from the quota.

For this specific policy, the impact on five different farm size groups are being examined. These different farm size groups are dairy farms with: 20-49 head of milk cows (group 1), 50-99 head of milk cows (group 2), 100-199 head of milk cows (group 3), 200-499 head of milk cows (group 4), and 500 or more head of milk cows (group 5). The total market supply of milk produced by these five size groups can be represented by the equation

$$Q_M^G(1-\gamma_M) = Q_1^G(1-\gamma_1) + Q_2^G(1-\gamma_2) + Q_3^G(1-\gamma_3) + Q_4^G(1-\gamma_4) + Q_5^G(1-\gamma_5) \quad (4.1.1)$$

where:

Q_M^G = total market supply of milk under unrestricted production growth (no quota),

γ_M = reduction in total market milk production from the quota,

Q_i^G = supply of milk under unrestricted production growth (no quota) for farm size group i,

γ_i = reduction in milk production from the quota for farm size group i.

Total market demand for milk is a function of the price consumers pay under the quota and can be shown by the equation

$$Q_M^D = D(P_M^1) \quad (4.2)$$

where:

Q_M^D = market demand,

P_M^1 = the equilibrium market price under the quota.

The market for milk will clear at the point where demand under the quota is equal to the total supply under the quota; this market-clearing condition is shown by the equation

$$Q_M = Q_M^G = Q_M^D \quad (4.3)$$

where:

Q_M= equilibrium quantity of milk,

Q_M^G = market supply under the quota.

To calculate the welfare impacts of the quota on different constituencies, equations for the relative change in the quantity of milk produced and demanded, and relative changes in prices must be derived first. In order to do this, the first step is to substitute the market clearing condition into both the market supply equation (Equation (4.1.1)) and the market demand equation (Equation (3.2)), which produces the following equations:

$$Q_M = Q_M^G(1-\gamma_M) = Q_1^G(1-\gamma_1) + Q_2^G(1-\gamma_2) + Q_3^G(1-\gamma_3) + Q_4^G(1-\gamma_4) + Q_5^G(1-\gamma_5) \quad (4.4)$$

$$Q_M = D(P_M^1) \quad (4.5)$$

To determine the impact of the quota on different constituencies, we need to know the relative change in the equilibrium quantity of milk from the quota. This can be derived from our supply and demand equations above (Equation (4.4) and Equation (4.5)). First, those equations are totally differentiated which gives us the total change in equilibrium quantity. Then, both sides of the differentiated equations are divided by the original market equilibrium quantity of milk (Q_M^G) which gives us the change in equilibrium quantity under the quota relative to the original equilibrium quantity without the quota in place. Completing these steps for the supply equation results in the following equation

$$dlnQ_M = \frac{dQ_M}{Q_M} = -\gamma_M = -k_1\gamma_1 - k_2\gamma_2 - k_3\gamma_3 - k_4\gamma_4 - k_5\gamma_5 \quad (4.6)$$

where:

$dlnQ_M$ = the relative change in the equilibrium quantity of milk,

k_i = share of total milk production produced by farm size group i.

One additional step is required for converting the demand equation (Equation (4.5)) to relative changes. The equation is still totally differentiated and both sides are still divided by the original market equilibrium quantity of milk (Q_M^G), but the equation is also multiplied by $\frac{P_M}{P_M}$ (or 1) so that the right-hand side can be written in terms of demand elasticity. Completing these steps results in the equation:

$$\partial lnQ_M = \eta_M \times \partial lnP_M \tag{4.7}$$

where:

$\partial lnQ_M =$ the relative change in the equilibrium quantity of milk,

$\eta_M =$ the market demand elasticity for milk,

$\partial lnP_M =$ the relative change in the market equilibrium price under the quota.

After converting to relative changes, the new system of equations is

$$\partial lnQ_M = -\gamma_M = -k_1(\gamma_1) - k_2(\gamma_2) - k_3(\gamma_3) - k_4(\gamma_4) - k_5(\gamma_5) \tag{4.6}$$

$$\partial lnQ_M = \eta_M \times \partial lnP_M \tag{4.7}$$

To see how these two above equations are derived step by step, see Appendix 1. Now Equation (4.7) can be rewritten to solve for the relative change in the market equilibrium price; doing this produces the equation,

$$\partial lnP_M = \frac{\partial lnQ_M}{\eta_M} \tag{4.8}$$

where:

$\partial lnP_M =$ the relative change in the market equilibrium price under the quota,

$\eta_M =$ the market demand elasticity for milk.

We can substitute Equation (4.6) into Equation (4.8) to produce the following equation

$$\partial lnP_M = \frac{-k_1(\gamma_1) - k_2(\gamma_2) - k_3(\gamma_3) - k_4(\gamma_4) - k_5(\gamma_5)}{\eta_M} \tag{4.8}$$

Remember that the change in producer surplus is defined as area J or areas H+I in Figure 4.1 (above). This are can be calculated by taking one-half multiplied by the base (ex. $Q_L^G - Q_L^1$ for area H) multiplied by the height of the triangle (ex. $P_M^0 - P_L^2$ for area H). To calculate the impact of the quota on farmers, a measurement for the change in the price where supply kinks to be vertical (P_i^2) is needed. This can be derived by starting with a general supply equation such as

$$Q_i^S = S_i(P_i^2) \tag{4.9}$$

where:

$Q_i^S =$ the quantity of milk supplied by farm size group I,

$S_i(P_i^2) =$ the supply of farm size group I as a function of P^2 for that size group.

By totally differentiating the above equation, dividing by the original market equilibrium quantity of milk (Q_M^G), and multiplying by 1 ($\frac{P_i^2}{P_i^2}$), we arrive at the equation

$$\partial lnQ_i^G = (\varepsilon_i)\partial lnP_i^2 \tag{4.9.2}$$

where:

∂lnQ_i^G = the relative change in the quantity of milk supplied by farm size group i,

ε_i = the supply elasticity for farm size group i,

∂lnP_i^2 = the relative change in the price where supply kinks vertically for farm size group i.

The above equation can be rewritten to get

$$\partial lnP_i^2 = \frac{\partial lnQ_i^G}{\varepsilon_i} \tag{4.9.3}$$

Since the relative change in the quantity produced for each farm size group is equal to the reduction in milk production under the quota for each farm group (i.e., $\partial lnQ_i^G = \gamma_i$), we can rewrite the above equation for each farm size group as

$$\partial lnP_i^2 = \frac{\gamma_i}{\varepsilon_i} \tag{4.10}$$

Now all the components essential for computing the changes in producer and consumer welfare have been derived. The change in producer surplus for each farm size group is represented by Equation (4.11) and Equation (4.12) below:

$$\Delta PS_i = (P_M^0 \times Q_i^0)\left\{-[dlnP_M^1] + \left[\frac{1}{2}(\gamma_i)\left(-\frac{\gamma_i}{\varepsilon_i}\right)\right]\right\} \tag{4.11}$$

where:

$\Delta PS_i = the\ change\ in\ producer\ surplus\ for\ farm\ size\ group\ i,$

$P_M^0 = the\ initial\ market\ equilibrium\ price\ for\ fluid\ milk,$

$Q_i^0 = the\ initial\ quantity\ of\ milk\ supplied\ by\ farm\ size\ group\ i.$

When estimating the impacts of the quota on different producer groups, we want to use the relative change in producer surplus because if we use the absolute measure of the change in producer surplus (Equation (4.11)) above), the results will be skewed by the initial quantity of milk supplied by each farm size group. If one group supplies a large share of all milk production, then their absolute change in producer surplus may show them gaining/losing the most from the quota while in relative terms they could be gaining/losing less than other farm size groups. The relative change in producer surplus is shown below in Equation (4.12):

$$\frac{\Delta PS_i}{P_M^0 Q_M^0} = \left\{-[dlnP_M^1] + \left[\frac{1}{2}(\gamma_i)\left(-\frac{\gamma_i}{\varepsilon_i}\right)\right]\right\} \tag{4.12}$$

where:

$dlnPS_i = the\ relative\ change\ in\ producer\ surplus\ for\ farm\ size\ group\ i.$

The change in consumer surplus is calculated using the following equation:

$$\Delta CS = -\left(P_M^\theta \times Q_M^\theta\right)\{[dlnP_M^1]\} \times \left[1 - \frac{1}{2}(\gamma_M)\right] \tag{4.13}$$

where:

$\Delta CS = the\ change\ in\ consumer\ surplus.$

To determine whether society as a whole is positively or negatively impacted, the deadweight loss of the quota is calculated using the following equation:

$$DWL = \left[\frac{1}{2}(P_M^0 \times Q_M^0)(\gamma_M)\right] \times -\left[(dlnP_M^1) - \left(-\frac{(\gamma_M)}{(k_1 \times \varepsilon_1 + k_2 \times \varepsilon_2 + k_3\varepsilon_3 + k_4\varepsilon_4 + k_5\varepsilon_5)}\right)\right] \text{ (4.14).}$$

4.4.2 Model Parameter Values

Now that the above equations have been derived, simulations can be run to quantify the impact of a range of growth-based production quota scenarios on the different farm size groups, consumers, and society as a whole. A growth-based production quota is analyzed because, again, that was the style of production control that had more support among producers.

The impacts are measured using the relative change in producer surplus, the change in consumer surplus, and deadweight loss. Table 4.2 (below) lists the different scenarios of growth-based production quotas analyzed by the simulations.

Table 4.2 – Model Growth Scenarios

Scenario Number	Level of Growth in Milk Production Allowed Under the Quota for All Farm Size Groups (G)
1	-0.02
2	-0.0175
3	-0.015
4	-0.0125
5	-0.01
6	-0.0075
7	-0.005
8	-0.0025
9	0.00
10	0.0025
11	0.005
12	0.0075
13	0.01
14	0.0125
15	0.015
16	0.0175
17	0.02

Within the model, certain parameters remain constant at fixed values while others vary within specified ranges. Table 4.3 (below) displays the values for the various parameters and the sources of their values are described in the text following the table.

Table 4.3 – Parameters Used in Model Simulations

Parameter	Description	Value(s)
Fixed Parameters		
Q_M^0	Initial market-level milk production for the United States (million lbs)	218
k_i	Share of U.S. milk production for farm size group i (where i = 1, 2, 3, 4, 5)[1]	0.038 *(i=1)* 0.098 *(i=2)* 0.100 *(i=3)* 0.120 *(i=4)* 0.641 *(i=5)*
R_i^{2000}	Growth rate of farm size group i in 2000 (where i = 1, 2, 3, 4, 5)[1]	-0.139 *(i=1)* -0.026 *(i=2)* 0.022 *(i=3)* 0.034 *(i=4)* 0.056 *(i=5)*
R_i^{2016}	Growth rate of farm size group i in 2016 (where i = 1, 2, 3, 4, 5)[1]	0.009 *(i=1)* 0.005 *(i=2)* 0.002 *(i=3)* 0.038 *(i=4)* 0.014 *(i=5)*
Varying Parameters		
P_M^0	Initial market price for fluid milk from U.S. producers	U(15, 21)
ε_i	Elasticity of supply for fluid milk for farm size group i (where I =1, 2, 3, 4, 5)[1]	U(0.5, 0.55) *(i=1, 2)* U(0.7, 1.04) *(i=3, 4, 5)*
η	Domestic demand elasticity for fluid milk facing U.S. producers	{-0.113, -0.50}
G	Rate of growth allowed under the mandatory quota	See Table 4.2
γ_i^{2000}	Reduction in production for farm size group i in 2000 (where i = 1, 2, 3, 4, 5)[1]	$(R_i^{2000} - G)$
γ_i^{2016}	Reduction in production for farm size group i in 2016 (where i = 1, 2, 3, 4, 5)[1]	$(R_i^{2016} - G)$

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[1] Farm size groups are as follows: 1 = 20-49 milk cows, 2 = 50-99 milk cows, 3 = 100-199 milk cows, 4 = 200-499 milk cows, 5 = 500+ milk cows

The initial market-level milk production (Q_M^0) for the United States is set using the 2019 national total milk production from the USDA's Milk Production Report (USDA 2020).

The share of U.S. milk production for each farm size group (k_i) is calculated using 2016 data from the USDA ARMS special tabulation. A total number of milk cows for each farm size group is found by taking the maximum number of cows milked on average for the size group multiplied by the number of farms represented by each farm size group. This number is then divided by the total number of milk cows for all farm size groups to find the share of milk cows in each size group; this share is used as a proxy for the share of milk production because milk production per cow is fairly uniform in the U.S.

The two estimates for the demand elasticity for fluid milk facing U.S. producers (η) come from two different sources. A more inelastic estimate that does not account for the effect of international trade comes from a USDA report to Congress in which they estimated the own-price elasticity of fluid milk from 1995 to 2017 in the U.S. (USDA 2017). A less inelastic estimate for the demand elasticity that attempts to take into account the effects of international trade is based on the work of Alston where they estimated the aggregate demand elasticity for agricultural output to be -1.0 (2010, 86). Since a rather small proportion of dairy products are exported and many dairy products have a short shelf life and cannot be exported easily, it was assumed that the total demand elasticity facing U.S. dairy producers for fluid milk is less elastic, leading to -0.5 being used as an estimated demand elasticity in the model.

The growth rates for each farm size group in 2000 (R_i^{2000}) and 2016 (R_i^{2016}) are also calculated using data from the USDA ARMS special tabulation on mean beginning and ending milk cow inventories for each farm size group.

Initial market price for fluid milk (P_M^0) is randomly generated from a uniform distribution that ranges between the level of prices experienced by producers over the last 5 years ($15/cwt to $21/cwt).

The elasticity of supply for fluid milk (ε_i) is based on the work of Chung, Chanjin, and Kaiser where they estimated intermediate supply elasticities for both small and large farms in the state of New York (2000). Chung, Chanjin, and Kaiser estimated 5-year and 10-year supply elasticities for farms with fewer than 100 cows and for farms with 100 or more cows (2000); their work is one of the only pieces that estimate elasticities for both small and large U.S. farms. In the model, the supply elasticity for farms with 20-99 milk cows (farm size groups 1 and 2) is set to randomly generate from a uniform distribution which ranges between the 5 and 10-year estimates of Chung et al for small farms (2000). The supply elasticity for farms with 100 and more cows (farm size groups 3, 4, and 5) in the model is set to randomly generate from a uniform distribution which ranges between the 5 and 10-year estimates of Chung et al for large farms (2000).

The rates of growth allowed under the various quota scenarios (G) are based on the fact that U.S. milk production has been generally been growing less than 2 percent and any quota enacted would likely be based around that trend. Note that when the growth allowed under the quota is less than 0 percent, that translates to a requirement that producers must reduce their production by that specified amount.

The variables representing the reductions in milk production for each farm size group (γ_i^{2000} and γ_i^{2016}) are determined by the rate of growth allowed under the quota and the growth rates for each farm size group in 2000 and 2016. The reduction in production for a group is found by taking their growth rate and subtracting the rate of growth allowed under the specific quota scenario. For example, if a farm size group is growing 3 percent and the quota allowed 2 percent growth, then that farm size group would have to reduce production by 1 percent. If the result of this calculation is negative, then the reduction in production is set to 0 because a farm size group would not be mandated to increase production under a growth-based quota, just simply allowed to increase.

4.5 Numerical Model Simulation Results

4.5.1 Welfare Impacts of Various Growth-Based Milk Production Quotas

For each quota scenario, 5,000 simulations are run using growth rates and reductions in production from the 2016 ARMS data. The simulations assume the demand elasticity is the domestic demand elasticity from Table 4.3 (above). The mean relative changes in producer surplus for all farm sizes in all quota scenarios using 2016 data are shown below in Figure 4.2.

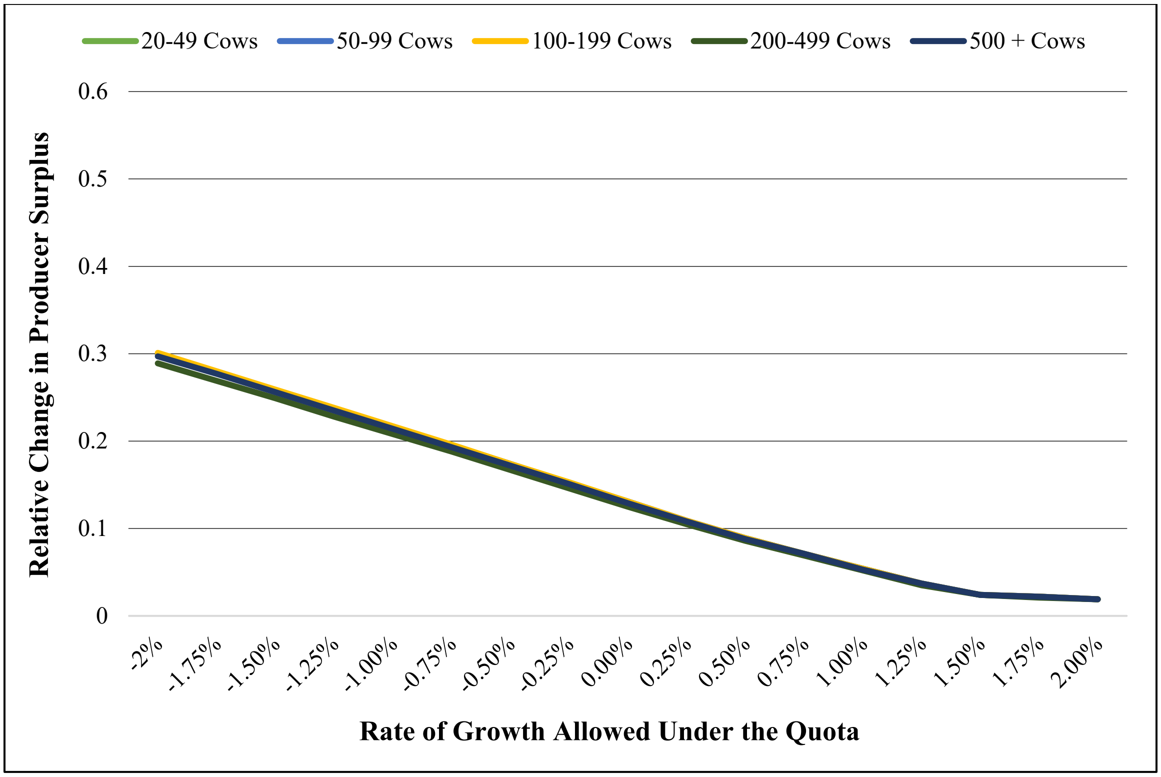

Figure 4.2 – Relative Quota Impacts on Producers Using 2016 Growth Rates

Note: the above figure shows the results when using a demand elasticity of -0.113

As can be seen in the above figure, the relative change in producer surplus is quite similar for all farm size groups across all the different quota scenarios. A primary factor in determining the impact of the quota on different producer groups is the relative change in the market price of fluid milk. Since this is the change in the market price, and all producers receive the same market price, this factor is the same for all farm size groups and leads to a strong similarity in the relative impacts of the quota. Another likely contributor to this similarity is the close range of the reductions in milk production for the different farm size groups in 2016. The three smallest size groups all had growth rates less than 1 percent and all within 1 percent of each other in 2016. In fact, the largest difference in the reductions between these groups is 0.7 percent. The two largest farm size groups had growth rates within 2.5 percent of each other and so their reductions in production were all within 2.5 percent of each other. Once the quota allows growth of 1.5 percent or more and exceeds the growth rate of all but one farm size group, the reductions in production for the other four farm size groups drop to 0, increasing the similarity of the reductions. Outside of the reductions in production, another parameter that affects the variation in the impact of the quota on different producer groups is the supply elasticity for each size (see Equation (4.12)) above). While two different supply elasticities are assigned to different size groups of farms, the reductions in milk production are again involved in this portion of the calculation for the impact on a group of producers, reducing the variation.

The above Figure also shows declining increases in producer surplus as the rate of growth allowed under the quota increases. When the quota actually requires farms to reduce production (i.e., a negative rate of growth allowed under the quota), there is an increase in the relative change in producer surplus for all farm groups of around 0.3, that value drops to near 0 as the rate of growth allowed under the quota approaches a positive 2 percent. This is caused by the fact that as the growth rate allowed under the quota increases from 0 percent, the quota scenarios begin to exceed the growth rates of the different farm size groups and the reductions in production decrease or become 0. Since the level of milk production is not changing as much, there is a smaller increase in the market price for fluid milk and so the farm size groups are reaping less of a benefit. The relative increase in producer surplus approaches but does not reach 0 in any of the quota scenarios because even when the quota allows for 2 percent growth, the second-largest farm size group is growing more than that so there is still a reduction in total milk production, causing the market price to rise and all producers to reap some benefit.

It is also important to analyze the impacts of a growth-based production quota on the different farm size groups if those farms were growing at rates that were greater in magnitude than they were in 2016 for all but one farm size group, like they were in 2000. For each quota scenario, 5,000 simulations are run using growth rates and reductions in production from the 2000 ARMS data. The simulations assume the demand elasticity is the domestic demand elasticity from Table 4.3 (above). The mean relative changes in producer surplus for all farm size groups in all quota scenarios using 2000 data are shown below in Figure 4.3.

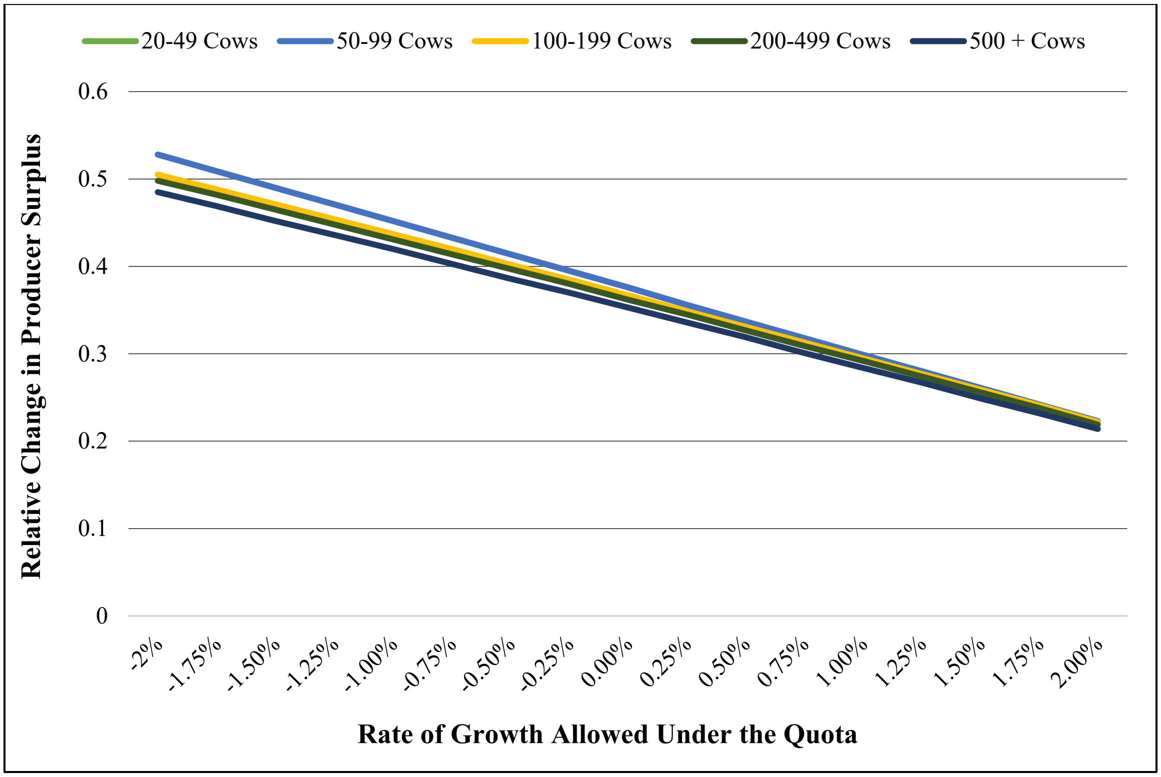

Figure 4.3 – Relative Quota Impacts on Producers Using 2000 Growth Rates

Note: the above figure shows the results when using a demand elasticity of -0.113

As the Figure above shows, using the growth rates from the 2000 ARMS data, the relative change in producer surplus is higher for all farm size groups in all quota scenarios compared to when 2016 growth rates were used earlier. Since the growth rates were higher in 2000 for 2 of the 3 largest farm size groups, that leads to larger reductions in production for those 2 groups and a larger total reduction in production which then turns into a greater increase in the market price. As a result, all farm size groups are reaping a greater benefit in all quota scenarios. Note how unlike before when the 2016 growth rates were used, the relative change in producer surplus here does not approach 0 as the rate of growth allowed under the quota increases. There is still a decreasing trend to the relative changes in producer surplus for the same reasons as described for Figure 4.2. A large reason for this is that the 3 largest farm size groups were growing more than 2 percent so in all quota scenarios there is still a reduction in production for all 3 of those groups whereas in 2016 there was a reduction in production for only 1 of these 3 groups, leading to a greater increase in the market price and therefore more benefits to all the producer groups using growth rates from 2000. In 2000, farms with 20-49 milk cows were shrinking by nearly 14 percent instead of growing and farms with 50-99 milk cows were shrinking by about 3 percent. Consequently, they do not have to cut back production by an additional amount (any more so than what they are already shrinking by annually) but still get to reap the benefits of having the higher market price for fluid milk that results from the reductions in production by farms with 100+ cows. Therefore, these 2 groups (20-99 cows) are seeing a greater relative increase in producer surplus than the other 3 farm size groups. Note that the line for 20-49 cows follows the exact same points as the line for 50-99 cows in the figure above because they both are reaping the full benefits of the higher market price since their reductions are 0 while they are not 0 for the other groups, this is why the line for 20-49 cows does not seem to appear on the graph above.

4.5.2 Effect of More Elastic Demand on Model Results

Since some dairy products are still exported (2 billion pounds in 2019 – see Figure 1.4), the total demand elasticity facing U.S. producers is likely more elastic than the domestic demand elasticity when accounting for the effects of international trade; this could alter the true impacts of a growth-based production quota on different size groups of producers. To determine the impacts of a growth-based quota if demand is truly more elastic, 5,000 additional simulations are run using growth rates and reductions in production from the 2016 ARMS data; these simulations now assume that the demand elasticity is the total demand elasticity from Table 4.3 (above). The results of these simulations are displayed below in Figure 4.4.

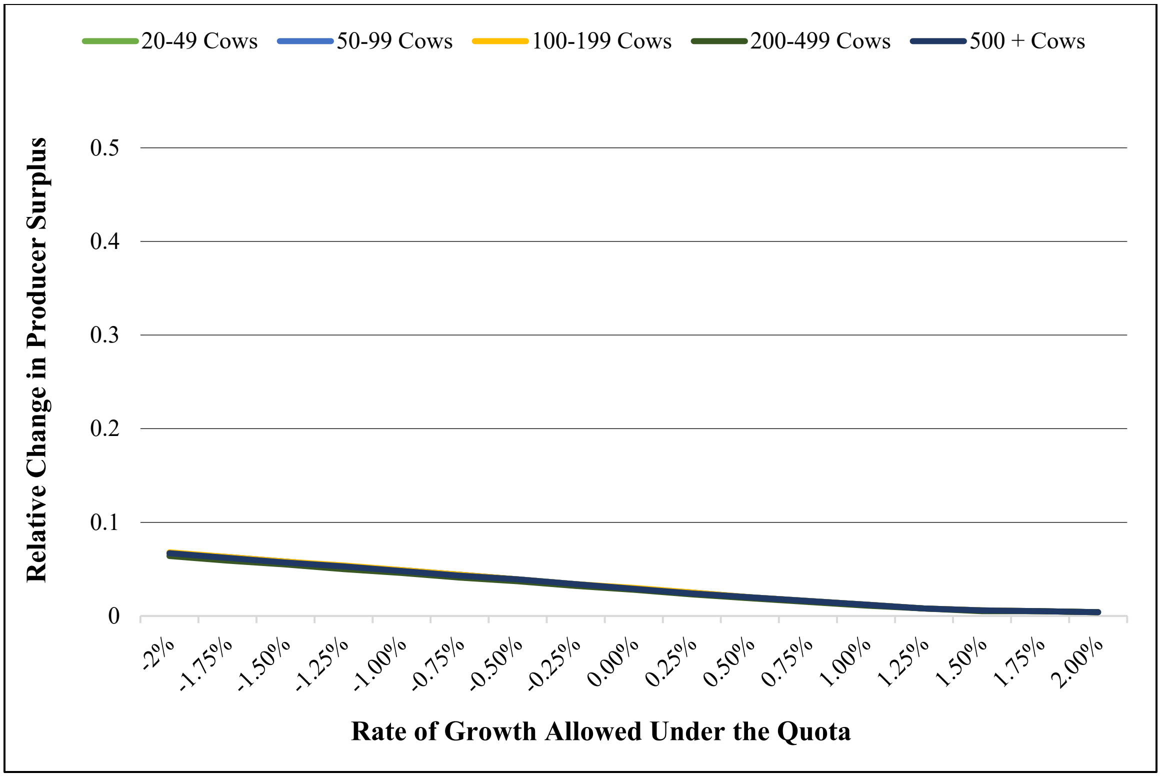

Figure 4.4 – Producer Impacts When Demand is Less Inelastic (2016)

Note: the above figure shows the results when using 2016 growth rates and a demand elasticity of -0.5

A primary difference between the above Figure 4.4 and Figure 4.2 is the steeper slope and consistently higher relative changes in producer surplus seen in Figure 4.2 where the demand elasticity was nearly 5 times more inelastic than the elasticity used for the results shown in the Figure above. Across all quota scenarios, the relative change in producer surplus is between 0.1 and 0 while with more inelastic demand those changes ranged between 0.3 and 0 across the various scenarios. With more elastic demand, the relative change in the market price for fluid milk is substantially lower; this can be seen in Equation (4.8) above. When the demand becomes more elastic, the denominator of this equation increases, causing the total relative impact on the market price to decrease. Demand is likely more elastic because the US is not the only producer of dairy products and so if prices increase in the U.S., then buyers will potentially purchase elsewhere and so anything the U.S. does to limit domestic production likely does not have as great of an impact on prices. Intuitively, when demand is more elastic and international trade is considered, reductions in production domestically are likely to only decrease exports and not change much of domestic production, therefore having a smaller impact on the domestic market price.

5,000 additional simulations are ran using growth rates and reductions in production from the 2000 USDA ARMS data to determine the impacts of the quota under more elastic demand and higher growth rates. These simulations now assume that the demand elasticity is the total demand elasticity from Table 4.3 (above). The results of these simulations are displayed below in Figure 4.5.

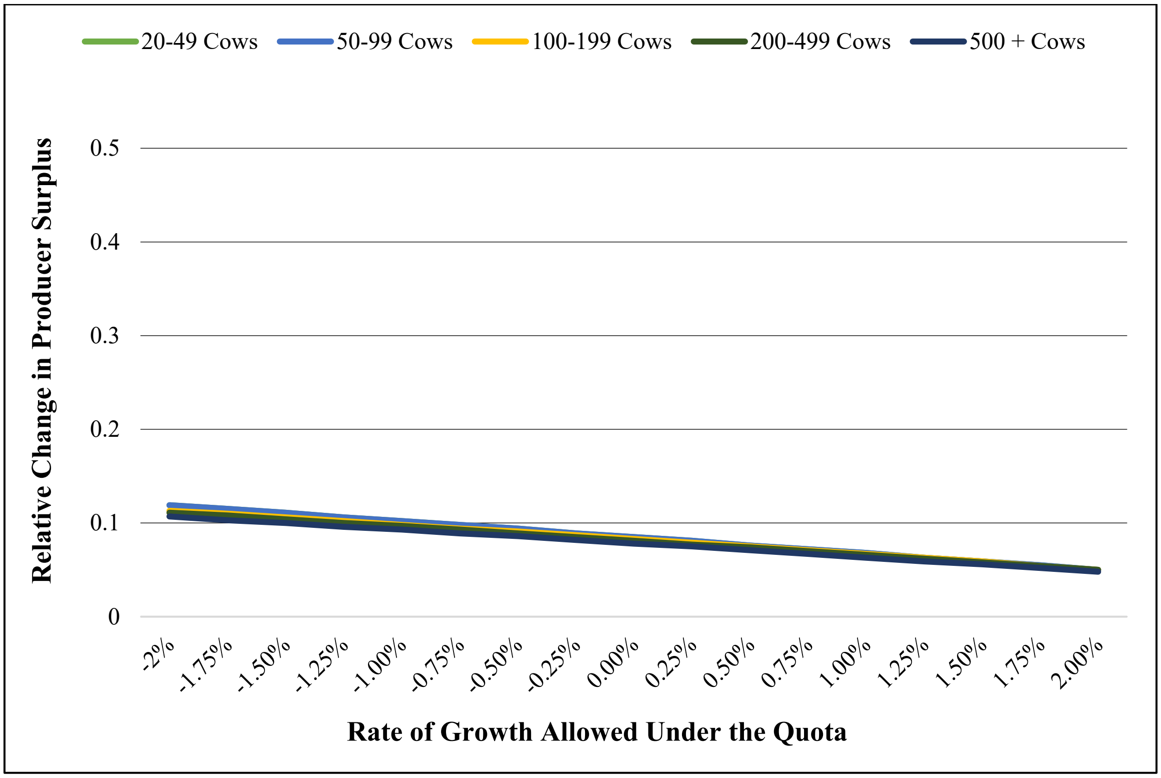

Figure 4.5 – Producer Impacts When Demand is Less Inelastic (2000)
Note: the above figure shows the results when using 2000 growth rates and a demand elasticity of -0.5

Again, in the Figure above there is a substantially lower relative increase in producer surplus across all quota scenarios when a more elastic demand parameter is used compared to a more inelastic demand parameter as in Figure 4.3. This reinforces the idea that if demand is truly more elastic, producers benefit substantially less than when demand is more inelastic.

In all the above results, producers benefit, even if very little, under all the quota scenarios. Also shown above, as the elasticity of demand for fluid milk increases, the benefits reaped by producers decreases under the quota scenarios. An interesting question then becomes how elastic does demand have to be for producers to actually be negatively impacted by a growth-based quota? To analyze this, we assume a quota scenario that allows for 0 percent growth and use the latest growth rates and reductions in production calculated from the 2016 USDA ARMS data. The demand elasticity was increased from -0.5 in 0.25 increments in each simulation of the model. The demand elasticity had to be increased all the way -18.00 before the mean impact on any one producer group turned negative. An implication of this is that if demand for fluid milk and dairy products is highly elastic, all sizes of dairy producers are likely to benefit from a production quota, even if that benefit is rather small.

4.5.3 Absolute Impacts of a Growth-Based Quota

Relative changes in producer surplus are used to analyze the impacts of the different quota scenarios in order to enable fair comparisons of the impacts across different size groups. When using the absolute change in producer surplus (which is the relative change in producer surplus multiplied by the initial market price and initial quantity of milk production for each size group) the results can be skewed since the larger farm size groups have such a larger initial quantity of milk production compared to small size groups. However, farmers and producer groups may still be interested in the total change in producer surplus under the quota. Figure 4.6 below illustrates the absolute change in producer surplus under three different quota scenarios (note these results utilize the 2016 growth rates for each farm size group and 5,000 simulations are again run). A less inelastic demand parameter (η) of -0.5 is utilized in these simulations to show the lower end of what dairy farmers are expected to gain from the quota. If demand is truly inelastic then the mean total change in producer surplus would be higher, although the declining trend as the allowed growth rate increases would remain. The results of these simulations are visualized below in Figure 4.6.

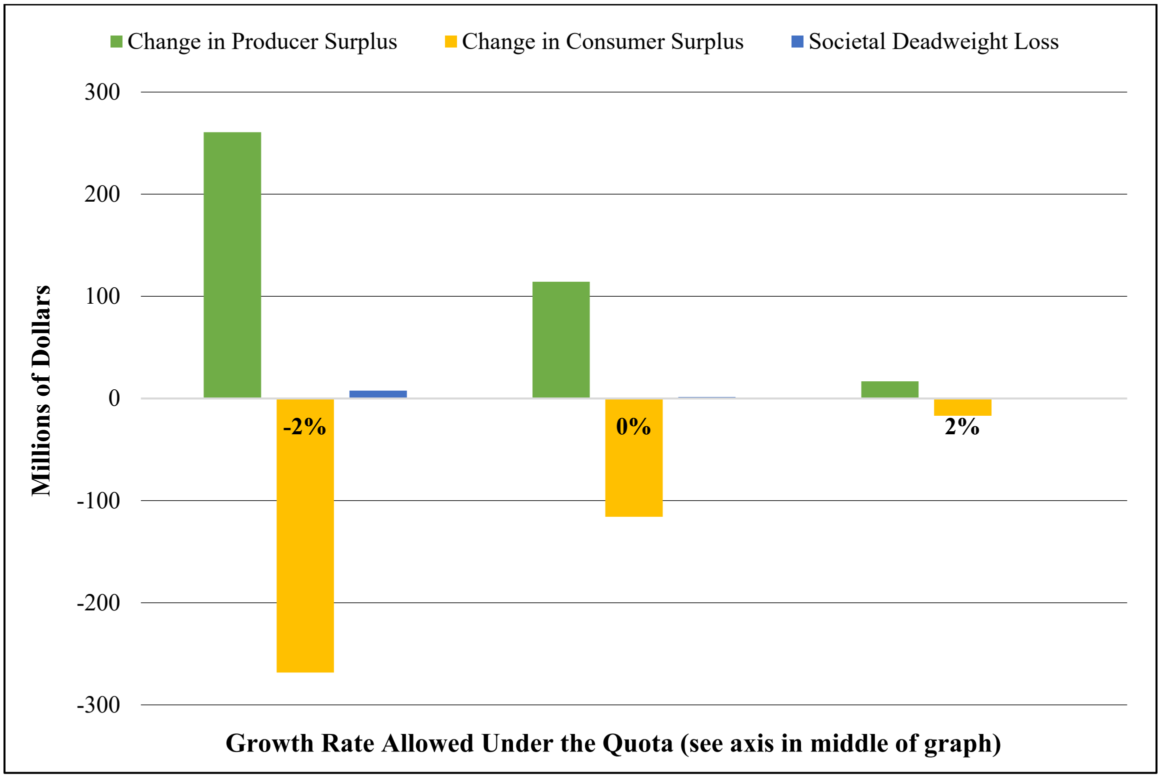

Figure 4.6 – Growth-Based Production Quota Impacts on Farmers, Consumers, and Society

Note: the above figure shows the results when using 2016 growth rates and a demand elasticity of -0.5

As can be seen in the above figure, the total absolute change in producer surplus falls substantially as the growth rate allowed under the quota increases, but they still benefit under all the scenarios. Even when the growth rate allowed under the quota exceeds the growth rate of all but one of the five farm size groups, producers are still seeing their welfare increase by nearly 17 million dollars.

The change in consumer surplus on the other hand rises as the allowed growth rate increases. Intuitively this makes sense since as producers are seeing smaller rises in the market price and benefiting less, consumers are having to pay for smaller increases in the market price and therefore being negatively impacted by a lesser amount. When the quota requires a 2 percent drop in milk production, consumers see their welfare decrease by nearly 270 million dollars but when the quota allows for 2 percent growth in production, they experience a decrease of only 17 million dollars.

An interesting trend from the above figure is how there is very little deadweight loss to society under all the quota scenarios. The greatest deadweight loss is around 8 million dollars under the most restrictive quota scenario and this value falls to nearly $30,000 when the quota allows for 2 percent growth. An implication of this is the quota essentially transfers welfare from consumers to producers in all scenarios.

4.5.4 Variation in the Relative Change in Producer Surplus

To get an idea of how much the variation built into the supply elasticities and initial market price varies the outcomes of the model, a particular quota scenario and farm size group are focused on. Using a quota scenario of 0 percent annual growth in milk production allowed, a demand elasticity of -0.113, and the second-largest farm size group (200-499 milk cows), 5,000 model simulations are run. Note that the second-largest farm size group was chosen for no particular reason and was selected at random. All of the results were within 0.00035 of each other, showing strong consistency of the results even with the built-in variation in the supply elasticities and initial market price. The most common results were within 0.00001 of each other.

4.5.5 Potential Reasons for Limited Support of Production Controls

If farmers are expected to gain under all the various quota scenarios, then why is there not more widespread support for production controls in the dairy sector? One possible reason is potential concerns regarding farm expansion potential under a production control. If a farm has been rapidly expanding their milk cow herd size and production by a rate of 5 percent annually, then a mandatory policy comes into effect telling them they are limited to annual growth of less than that, it is understandable how that farmer could strongly oppose the policy. Farmers who have been rapidly growing could be opposed to a production control for the U.S. dairy sector because they do not want the government deciding how much they can grow annually, despite the results above suggesting they would benefit under the policy.

Additionally, with the quota, the U.S. would likely have to impose a tariff on dairy product imports to limit consumers from switching to cheaper options from other countries. Producers may be concerned that this could result in retaliatory tariffs on U.S. dairy product exports.

Concerns may also exist over the ability to enforce a production control. Production control programs in the past have not had significant impacts on production because non-participating farmers have increased their production during the period of the program. To avoid exceeding the allowable growth rate, a large dairy farm could simply break up its operation into smaller, separate entities that could then grow in smaller amounts while the total growth for the original farm remains the same. Any non-mandatory quota or even a mandatory quota could prove difficult to enforce enough to a point where production is significantly affected, and some farmers or industry groups may then not see it as an effective tool.

Another potential reason for opposition a production control among dairy farmers is the concern over possible consumer blowback. Since the quota would raise the market price of fluid milk, and therefore negatively impact consumers, farmers may be worried about a negative impact on consumers' view of the dairy industry. Consumers dealing with higher market prices may be opposed to other policies that come along in the future which support dairy farmers.

4.5.6 Additional Policy Implications for Dairy Farmers and their Employees

Different groups of dairy farms and dairy farm employees are likely to be affected by a growth-based production quota in different ways based on factors other than their size as well. Since under the quota, less milk production is expected, individuals who supply dairy farms with management and labor could be negatively impacted since there will be less demand for their services than there would be without the quota. Additionally, with the quota setting a limit on how much milk production can grow, it essentially restricts individuals from entering the industry and forming new dairy farms. Anyone who would like to start a dairy farm would not be able to unless the policy somehow factored in a way for still allowing new entrants into the market.

4.5.7 Political Economy Implications

In traditional dairy areas where farms have been around for a longer time and are likely growing less, farmers are likely to want their elected officials to support a growth-based production control to raise market prices while farmers in newer dairy areas where farms are younger and rapidly growing are likely to oppose any form of production control so they can continue expanding their herds and production.

Chapter 5 - Conclusion

Context for Research

Long periods of low milk prices in the U.S. dairy sector have led to divisive discussions of production control as a potential solution and this thesis provides valuable insight for dairy farmers, industry groups, and policymakers to consider when determining if a growth-based production quota would be beneficial to their industry.

Summary of Analysis

The work conducted in this thesis quantified the relationship between initial average farm sizes and growth rates of average farm size. A positive, statistically significant relationship was found to exist, suggesting that the larger a farm is, the more they are growing. Data from a special tabulation of the USDA ARMS in 2000 and 2016 also provided support that larger dairy farms are growing at faster rates than smaller dairy farms, although the rates of growth were increasing more for smaller farms.

An equilibrium displacement model is developed to analyze the impacts of a growth-based production quota on five different farm size groups. When using reasonable parameters found from the literature or conditions experienced by the industry in recent years, along with both inelastic and elastic demand, as well as annual growth rates from both 2000 and 2016, all five farm size groups experience a positive relative welfare impact from production quotas that range from requiring a 2 percent drop in production to allowing a 2 percent increase in milk production.

Summary of Implications

Some potential reasons for why some dairy farmers and industry groups are not in favor of production controls despite the evidence that this particular type of control would benefit all sizes of producers include concerns over farm size and production expansion, potential retaliatory trade impacts as well as potential consumer blowback. Smaller farmers or those not looking to expand (many of whom are likely in traditional dairy areas) are likely to be more in favor of a growth-based production control while larger and rapidly growing farmers (likely in newer dairy areas) are likely to be less supportive of this type of production control which could set up some interesting divisions of support and desire for policymakers to act.

Limitations

A couple of primary limitations of the research presented in this thesis are important to keep in mind when interpreting the results. One key limitation is that all of the data utilized to determine patterns and rates of growth in U.S. dairy farm size are aggregated at some level. The USDA's Census of Ag data provides county average dairy farm sizes while the special tabulation from the USDA's ARMS is aggregated across the various farm size groups. Using aggregated data could skew the growth rates calculated. For example, if a county has several small farms and one very large farm and that very large farm is growing rapidly while the smaller farms are shrinking, then the growth rate will primarily show the growth of the large farm and hide the shrinkage of the smaller farms. Ideally, to most accurately determine how different sizes of dairy farms are growing, one would be able to access data from individual dairy farms ranging from very small to very large and spread across the country.

A second important limitation relates to the partial equilibrium model utilized to determine the impacts of the quota. The model does not take into account the effects international trade has on the U.S. market for milk and other dairy products. While a smaller share of dairy products are traded internationally than other commodities, it would still be valuable to have a model that includes the international market as well as the domestic market so that one can find how the policy would affect both markets. When incorporating international trade, a production control of any kind is likely to be less favorable for U.S. dairy farmers. A primary reason for this is that when the international market is factored in, the elasticity of demand facing producers is likely more elastic. If demand is more elastic, then any change in the quantity of milk produced in the U.S. will have a relatively smaller impact on the overall world market price for milk than when just considering the domestic demand in the U.S.

Areas for Future Expansion

A primary area for further research would be to build an EDM to analyze a growth-based production control that also incorporates the complex milk pricing process under the FMMO system as it could change the degree to which farmers benefit. If a reliable estimate of a demand elasticity facing U.S. producers that fully accounts for the effects of international trade on domestic dairy producers can be found or derived, then it would be worthwhile to include that parameter in the model to get a potentially more accurate measure of the impact on both producers and consumers.

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Appendix A - Deriving the Relative Change in the Equilibrium Quantity of Milk

To convert Equation 4.4 into the relative change in milk production from the quota, the Equation is first fully differentiated which produces the following equation:

$$dQ_M = -Q_M^G \times d\gamma_M = -Q_1^G \times d\gamma_1 - Q_2^G \times d\gamma_2 - Q_3^G \times d\gamma_3 - Q_4^G \times d\gamma_4 - Q_5^G \times d\gamma_5 \quad (A.1)$$

where:

Q_M^G = total market supply of milk under unrestricted production growth (no quota),

γ_M = reduction in total market milk production from the quota,

Q_i^G = supply of milk under unrestricted production growth (no quota) for farm size group i,

γ_i = reduction in milk production from the quota for farm size group i.

Next, Equation A.1 is divided by the initial market equilibrium quantity of milk production to produce the following equation:

$$\frac{dQ_M^G}{Q_M^G} = dlnQ_M = -\frac{Q_M^G \times d\gamma_M}{Q_M^G} = -\frac{Q_1^G \times d\gamma_1}{Q_M^G} - \frac{Q_2^G \times d\gamma_2}{Q_M^G} - \frac{Q_3^G \times d\gamma_3}{Q_M^G} - \frac{Q_4^G \times d\gamma_4}{Q_M^G} - \frac{Q_5^G \times d\gamma_5}{Q_M^G} \quad (A.2)$$

where:

∂lnQ_M = the relative change in the equilibrium quantity of milk.

The above Equation can be rewritten as Equation 4.6 below:

$$dlnQ_M = \frac{dQ_M}{Q_M} = -\gamma_M = -k_1\gamma_1 - k_2\gamma_2 - k_3\gamma_3 - k_4\gamma_4 - k_5\gamma_5 \quad (4.6)$$

where:

$dlnQ_M$ = the relative change in the equilibrium quantity of milk,

k_i = share of total milk production produced by farm size group i.

To convert the demand equation (Equation (4.5)) to the relative change in equilibrium quantity of milk production, first the demand equation is totally differentiated which results in the following equation:

$$dQ_M = \frac{dD}{dP_M^1} \times dP_M^1 \qquad (A.3)$$

where:

P_M^1 = the equilibrium market price under the quota.

Equation A.3 is, like Equation A.1, divided by the original market equilibrium quantity of milk, but it is also multiplied by $\frac{P_M^1}{P_M^1}$ (or 1) to enable the right-hand side of the equation to be written in terms of the demand elasticity for fluid milk; this results in the following equation:

$$\frac{dQ_M^G}{Q_M^G} = dlnQ_M = \eta_M \times dlnP_M^1 \qquad (A.4)$$

where:

∂lnP_M = the relative change in the market equilibrium price under the quota,

η_M = the market demand elasticity for milk.