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An Econometric Analysis of U.S. Milk Production: A Herd Dynamics Model

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Keywords: milk supply, long-run elasticities, regional distribution of production, dairy policy, local development
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Abbreviations and Acronyms

CCC	Commodity Credit Corporation
cwt	hundredweight, 100lbs
EU	European Union
FMMO	Federal Milk Marketing Orders
GDP	Gross Domestic Product
GN	Gauss-Newton (algorithm)
lbs	pounds
MILC	Milk Income Loss Contract
MPSP	Milk Price Support Program
NASS	National Agricultural Statistics Service
US	United States (of America)
USA	United States of America
USD	United States dollar
USDA	United States Department of Agriculture

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Abstract

An Econometric Analysis of U.S. Milk Production: A Herd Dynamics Approach

We investigate the impacts of technological changes on supply structure of the US milk production. The econometric model used is based on aggregate annual U. S. data and is composed of three stochastic equations defining the size and herd structure of the U.S. dairy herd, average productivity and the heifer replacement rate and an identity equation defining total U.S. milk production as the product of herd size and average productivity. As our main contribution to existing literature, we have found a way to use bootstrap to test hypotheses regarding long-run price-responsiveness of supply, and we have found that 10-year elasticity of milk supply to milk price has decreased and that change in elasticity is statistically significant. We simulate the effects of different price scenarios on long-run U.S. milk supply. One finding is that using large quantities of feed stocks for bio-fuel production could affect significantly affect price of milk. We use the above results to indicate the consequences of changes in dairy policy in EU to local development. As EU abandons production quotas in milk production, we can expect strong consolidation and regional shifts in production. This can potentially have strong adverse impacts on local development in rural areas where small farms dominate.

Keywords: milk supply, long-run elasticities, regional distribution of production, dairy policy, local development
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Executive Summary

An Econometric Analysis of U.S. Milk Production: A Herd Dynamics Approach

The U.S. dairy industry is continuing to experience dramatic structural changes that started in the early 1970's. These include (i) changes in the dairy farm scale and technologies, (ii) the development of new value-added dairy products, (iii) the evolution of dairy policies that are arguably more market oriented than in the past and (iv) an increasing reliance on international markets for the resulting manufactured dairy products. This study has four main objectives: (i) quantify the current supply structure of the U.S. dairy industry, (ii) examine the impacts of technological changes that have occurred on the price elasticity of supply and specific herd characteristics such as culling rates, replacement rates, herd growth, etc., (iii) generate dynamic long-run forecasts of long-run milk supply response to price changes and possible future technological advancements, and (iv) use results to inform policy makers in EU about consequences changes in dairy policy will have on local development.

The econometric model used is based on aggregate annual U.S.data and follows the specification originally formulated by Chavas and Klemme (1986). The model is composed of three stochastic equations defining the size of the U.S. dairy herd, average productivity and the heifer replacement rate and an identity equation defining total U.S. milk production as the product of herd size and average productivity. In this model dairy herd dynamics are determined primarily by the culling and cow replacement decisions under an assumed profit maximization objective. The producer must make a decision with respect to which cows currently in the herd should be removed and sold for slaughter, and how many calves should be grown into replacement heifers and subsequently added to the herd. We adopt the standard assumption that heifers enter the herd when they are 2 years old, and the maximum productive lifetime of a dairy cow is 9 years in the herd. In a particular year, the farm operator makes a decision as to how many cows of each of the 9 productive age classes will be kept in the herd for another year. We model those decisions by logistic survival rates, S_{ti}, which represents the probability that in the t^{th} year a cow in the in i^{th} productive age class will survive one more year: $S_{ti} = 1 / \left(1 + e^{Z_{ti}\beta}\right)$ where the vector of explanatory variables, Z_{ti} reflects the state of technology in the t^{th} year, economic conditions, and age of that class at the time of selection decision and β is a coefficient vector to be estimated. The number of cows in the i^{th} productive age class is determined by the product of number of replacement heifers *i* years ago (HEF_{t-i}) and associated retention rate (R_{ti}) where $R_{ti} = \prod_{j=1}^{i} S_{t-j,i-j}$. We model replacement heifers via : $HEF_t = .5\left\{\left(COW_{t-2} + HEF_{t-2}\right) * \Gamma_t\right\}$ where $\Gamma_t = 1 / \left(1 + e^{W_t\eta}\right)$, W is a matrix of exogenous variables and η parameters to be estimated. Total herd size (COW_t) is calculated as the sum of cows in each of the nine productive age classes (COW_{ti}), where the number of cows in each age class equals the number of heifers i years ago times the associated survival rate: $COW_t = \sum_{i=1}^{9} COW_{ti} = \sum_{i=1}^{9}\left(HEF_{t-i} * R_{ti}\right)$. We estimate a stochastic yield equation which takes a simple linear form with technological change being the principal explanatory variable. Finally, estimate of the total U.S. milk production is obtained by multiplying estimate of the number of cows in the U.S. dairy herd with estimated average yield.

We estimate the above econometric model using annual aggregate U.S. data encompassing 1965 to 2007. The yield equation is estimated by OLS while the COWS and HEF equations are estimated via the Gauss-Newton algorithm within a nonlinear least squares estimation procedure. We use residuals-based bootstrapping, simulating the data generating process in the model, and percentile-t method to obtain bootstrap confidence intervals of parameter estimates and compare them with asymptotic confidence intervals. The estimated stochastic equations exhibit a high degree of in-sample prediction accuracy. We find predictable impacts of change in feed and milk price on herd size and dynamics: better economic conditions induce increased herd size as well as faster replacement of cows with new, and more productive heifers. Given the model structure we can calculate how cull rates of each cow productive age class reacts to prices. We find that cull rates elasticities have decreased significantly over the last two decades.

We test how long-term price responsiveness has changed over the last two decades. In this analysis we find that the large productivity gains resulting from improved genetics, housing management, feeding practices, etc. do not translate to higher long-run price responsiveness. On the contrary, we find evidence that 10-year elasticity of milk supply to milk price changes has decreased from an average of 1.36 over the 1978-1982 period to 0.86 over 2003-2007 period. As our main contribution to existing literature, we have found a way to use bootstrap to test hypotheses regarding long-run price-responsiveness, and we have shown that results defy conventional wisdom. We conclude that reduction in long-run price responsiveness is the result of more binding biological constraints which are manifested as higher replacement ratio needed to keep the herd size stable, and increase in involuntary cull rates. This latter result makes it difficult for farmers to increase the retention rate of cows in the process of adjustment to favorable changes in economic environment. Our analysis would imply that price-responsiveness will be asymmetric since biological constraints will be binding only in case where the dairy herd is expanding due to favorable economic environment.

We further exploit the structure of the model to simulate effects of different price scenarios on long-run U.S. milk supply. We simulate three trajectories, corresponding to “average”, “favorable” and “high-cost/unfavorable” scenarios. We find that high feed cost prices, experienced in summer 2008, if they stayed unchanged over the next 10 years, would lead to decade long stagnation in milk supply which would mark sharp departure from the sustained growth in milk supply experienced over a long history of US dairy industry. We use these simulation results to raise concerns of higher feed prices resulting from the use of large quantities of feed stocks for bio-fuel production.

Finally, we use the result to indicate the consequences of changes in dairy policy in EU to local development. As EU abandons production quotas in milk production, we can expect strong consolidation and regional shifts in production. This can potentially have strong adverse impacts on local development in rural areas where small farms dominate. We advise that in addition to productivity gains and technological improvements in dairy production goals such as food security and spatial cohesion be taken into account.

Acknowledgements

There are many people to whom I need to thank for enabling my work on this paper, and instead of pondering over the impossibility to rank them properly, I will cheat and use “order of appearance” method.

To my professor of macroeconomics and economic policy at University of Zagreb, prof. Ivo Bicanic, I thank for dual role he had. Not only did he instill in me the love for economic analysis, but he adamantly insisted that I go to graduate studies abroad, to gain skills and experiences “far from home”.

To my mentor at the Institute of Economics, Zagreb, Dr. Nenad Starc, I thank for organizing financial support for my studies in Italy and USA. Even more so, I thank you Nens for your friendship and patience in the early days where my curiosity and intellectual restlessness far outweighed my discipline and skills to ‘deliver a final product’. This work is a first step in that direction.

To prof. Giovanni Pegoretti at University of Trento, I thank for his willingness to allow me to change the topic of my Project Work for CoDe Master’s thesis so many times. As I had to leave Trento early to start doctoral program at University of Wisconsin-Madison, topic of this work necessarily accommodated to the hectic life of PhD studies. Professors Pegoretti and Master’s Academic Director Dr. Bruno Dallago were full of understanding for the situation and provided the necessary flexibility I needed to complete this research.

Big bold and underlined thanks goes to Dr. Brian W. Gould at University of Wisconsin-Madison who was my advisor and invaluable guide into nuts-and-bolts of advanced econometrics as much as intricate world of US agricultural policy and industry structure. This paper was developed during my work as research assistant for him in the period June 2007-September 2008. Brian was my first true contact with specific atmosphere of US academic world, where formalities are fully dropped but work ethic and discipline is at the top place.

I close my list expressing my gratitude to my parents for their love and my colleagues and friends at UW-Madison for teaching me how to balance work and joy, and live more fully.

1. Introduction

This work examines evolution of U.S. milk production and the dairy policy environment in which the industry operates. Paucity of recent econometric analysis of the topic, combined with staggering increases in productivity and changes in regional distribution of dairy farms in USA has prompted us to apply tools of economic analysis to investigate the structure of dairy industry in USA. Changes in milk production include: (i) changes in the dairy farm scale and technologies, (ii) the development of new value-added dairy products, (iii) the evolution of dairy policies that are arguably more market oriented than in the past and (iv) an increasing reliance on international markets for the resulting manufactured dairy products.

This study has four main objectives: (i) quantify the current supply structure of the U.S. dairy industry, (ii) examine the impacts of technological changes that have occurred on the price elasticity of supply and specific herd characteristics such as culling rates, replacement rates, herd growth, etc., (iii) generate dynamic long-run forecasts of long-run milk supply response to price changes and possible future technological advancements, and (iv) use results to inform policy makers in EU about consequences changes in dairy policy will have on local development.

In the second chapter we provide exensive overview of the features characterizing milk production in USA. We first examine demand trends and argue that market for dairy products in US is mature, but with aggressive innovation trends. We then describe changes in milk supply structure, outlining the dimensions of regional shifts in production, increases in cow productivity, and continued consolidation where small farmers exit the market and ever bigger stables are built with many thousand cows. US dairy policy is considered next, and two main pillars – Milk Price Support Program and Federal Milk Marketing Orders are examined in detail. Brief comparisons with EU policy follows. Chapter is closed by overview of economic environment in which dairy industry operates, characterized by long-run trends of decreasing real prices of both feed inputs and milk, as well as increased price volatility that followed introduction of more market-friendly government support policies.

In the third chapter, after literature review, we describe the econometric model used in this analysis. First we present brief primer on cow biology that drives the modeling assumptions. After that, we describe model equations in full detail. At the end of the chapter, provided is the careful examination of explanatory variables chosen and their link to the various aspects of economic environment they attempt to capture.

In the fourth section, we provide description of the data we used for empirical estimation. Where we have deviated from previously used definitions in classic articles, we provide clear reasons for the changes we introduced.

Fifth chapter describes the estimation procedures and results. We explain our choice for the estimation period, methods used to obtain global minimum of highly nonlinear objective function, and we describe bootstrap generation of simulated samples step-by-step. With the help of visual aids we illustrate the high predictive power of the model. Since coefficients enter in two stochastic equations via logistic function, we calculate marginal effects as a way to make more clear what their signs, magnitude and variance and really imply.

While direct interpretation of coefficients correspond to short-run analysis, our main interests lie in the long-run adjustments of milk supply to price changes. To that goal, in the sixth chapter we undertake long-run forecasting with scenario analysis to see how US milk production would react to persistent high prices of inputs as experienced in summer 2008. Principal, and very unexpected finding of this work is that productivity gains did not translate to higher long-run price responsiveness. We first describe that result, and then look deeper into predicted changes of herd structure to understand the causes of the decrease in long-term price elasticity.

Final chapter concludes by outlining the implications of these findings to local development. As gains in productivity come on the wings of reduction in number of farmers and big regional shifts in production to exploit comparative advantages, we argue that EU move towards more market friendly dairy policy needs to anticipate such outcomes, and address them having in mind food security and spatial cohesion goals.

2. Overview of U.S. dairy sector

"The cow is the foster mother of the human race. From the ancient Hindoo to this time the thoughts of men have turned to this kindly and beneficent creature as one of the chief forces of human life."

William D. Hoard, 1885

Walking through the aisles of the local supermarket, one cannot but be amazed at the variety of dairy products offered. Panoply of cheeses, staggering variety of yoghurts, milk skimmed and whole, butters, sour creams and other products for every market segment, budget or occasion. Dairy industry in USA today is modern, technologically advanced, and customer-oriented sector characterized by amazing speed of innovations in both milk production and final-products offered. This chapter seeks to present overview of fundamental trends in consumption, production and trade of milk and milk-based products. It outlines structural change, regional shifts in production, and technological innovations industry has faced in last half-century. Given is the overview of federal regulatory framework and economic environment in which farms operate. Here, we seek to lay ground by introducing industry's jargon, and the timeline of all variables used in econometric work in chapters 3-5. With the help of visual aids – graphs, tables, and flowcharts, we seek to tell the interesting story of U.S. milk industry.

2.1. Demand Trends

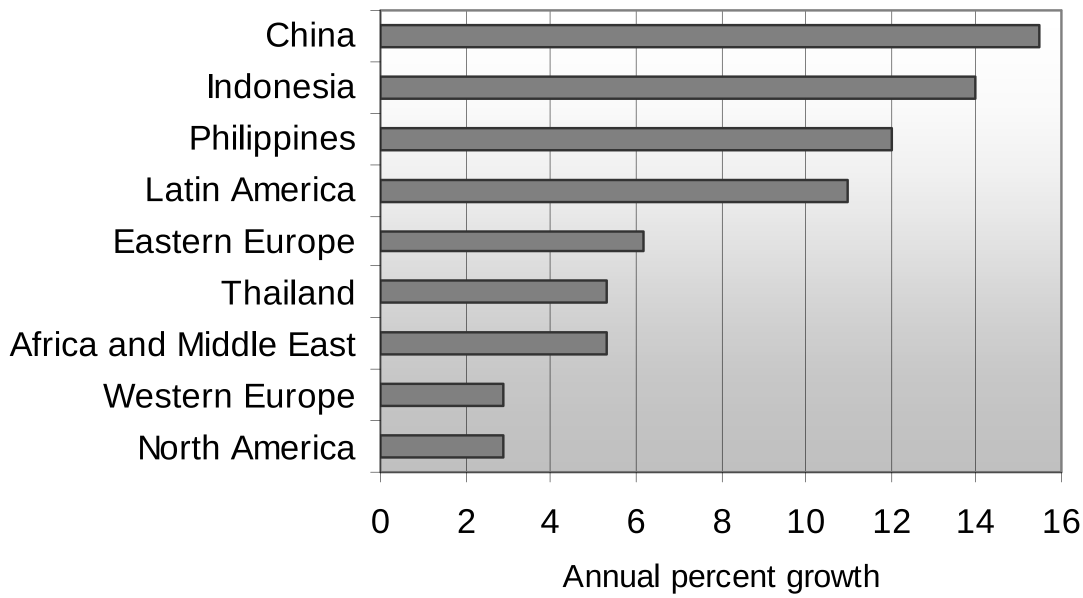
In USA in 2006, there were close to 80,000 milk farms producing 80 million liters of milk per year[1]. With more than 20 billion USD of revenues dairy sector accounts for 10% of US agricultural GDP[2]. With total demand growing by just 2.2% annually (market value of products sold), market for dairy products in US can be considered matured. To illustrate this, we compare demand growth for dairy products across nations. In figure 2.1., we

[1] USA uses English units measurement system, not SI (The International System of Units). Milk quantities are usually reported in pounds (lbs), 1 lbs=0.4536 kg, or gallons, 1 gallon= 3.7854 liters.
[2] Total US agricultural GDP comprises 0.9% of USA GDP.

see order-of-magnitude difference between emerging economies like China, and developed countries such as EU and USA.

Figure 2.1.

Average Annual Retail Growth of Expenditures for Dairy Products, 1998-2004

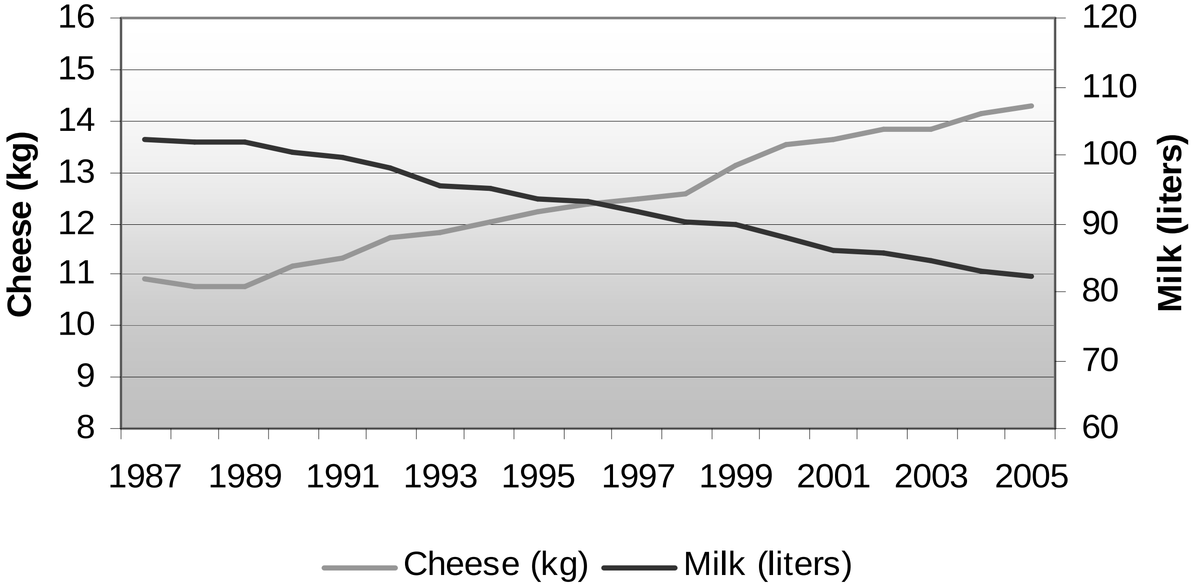


Source: Prepared by USDA, Economic Research Service using data from Euromonitor International. Reproduced from Blayney, D. et al. (2006): U.S. Dairy at a Global Crossroads. USDA.

Taking a closer look at USA in Figure 2.2., we notice that demand for fluid milk has in fact been falling, substituted by increased demand for higher value-added products, in particular cheese. In 1986, US per capita annual consumption of milk was 102.2 liters, totaling 24.54 billion liters. By 2006, per capita consumption of milk has fallen to 82.32 liters, with total production level virtually the same due to population increases over the same period. Same data for cheese markets reveals that per capita consumption has risen from 10.93kg in 1986 to 14.3kg in 2006. Taking into account population increase this change maps to an increase of over 50 percent in total production, with significant part of demand satisfied from imports for specialty cheeses.

Figure 2.2.

U.S. Per Capita Milk and Cheese Consumption, 1987-2005

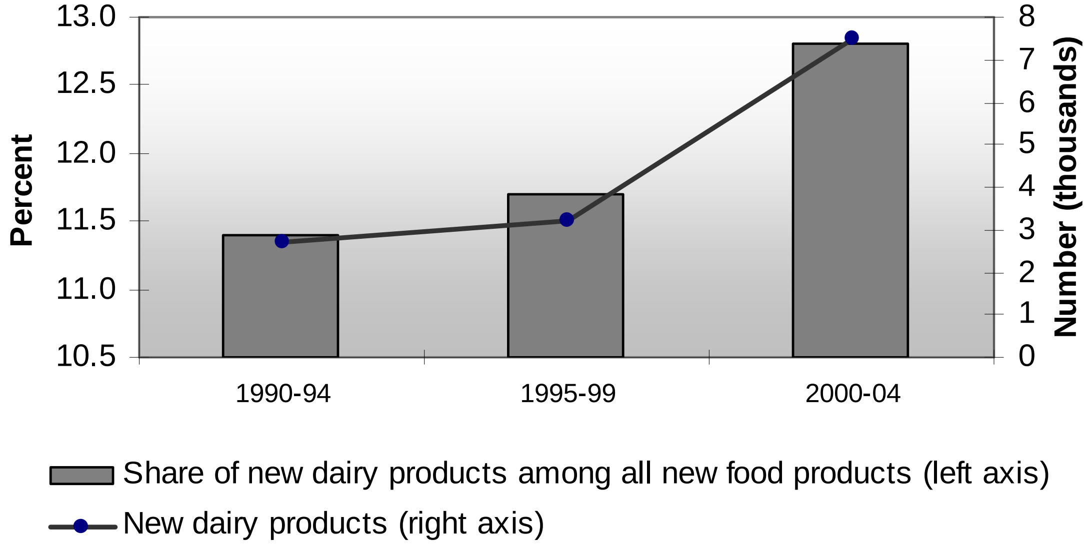


Source: http://future.aae.wisc.edu/tab/prices.html

For the producers of final products, saturated market for fluid milk means constant fight for market share in processed products, which, in conjunction with possibilities opened by new modern processing technology, implies necessity of constant end-product innovation. Figure 2.3. shows that new dairy products are gaining share among all new food products. In period 1990-1994, little less than three thousands new dairy product were introduced, figure that more than doubled to 7000 new products in the same length period one decade later. Correspondingly, share of new dairy products in all new food products increased in the same period from 11.4 to 12.8 percent, indicating both that innovation is present in other sectors as well, but reinforcing the conclusion that dairy sector is characterized by particularly intensive competitive forces

Figure 2.3.

New Dairy Products Introductions Increasing At Faster Pace than All New Food Products



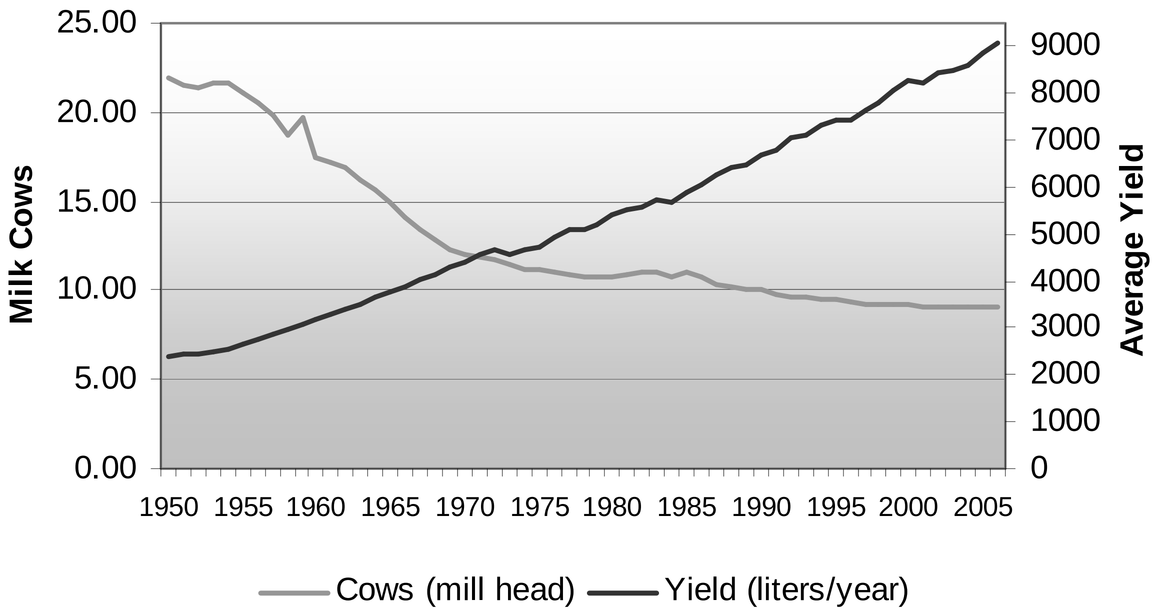
Source: Prepared by USDA, Economic Research Service using data from Datamonitor Productscan. Reproduced from Blayney, D. et al. (2006) U.S. Dairy at a Global Crossroads, USDA.

2.2. Supply Trends

The other side of the coin is, of course, the supply side. Emerging from World War II with no battles fought on its territory, USA faced gradual evolution in milk production, with no dramatic discontinuities. As seen in Figure 2.4., in 1950, national herd size was 21.94 million cows, and yield - average annual milk production per cow - was as little as 5,314 pounds (2410.3 liters, or 6.6 liters per cow daily). To current date, herd has halved, and the yield quadrupled to 19,951 pounds (9049 liters, or 24.8 liters a day). In the period 1950-2006, annual yield growth rate was 2.49%, while dairy cow herd was shrinking at the rate of -1.68%. Most of the herd reduction took place in 1950-1975, and in the last eight years number of cows has almost stabilized at the level of 9.1 million.

Figure 2.4.

U.S. Dairy Herd Size and Yield, 1950-2006

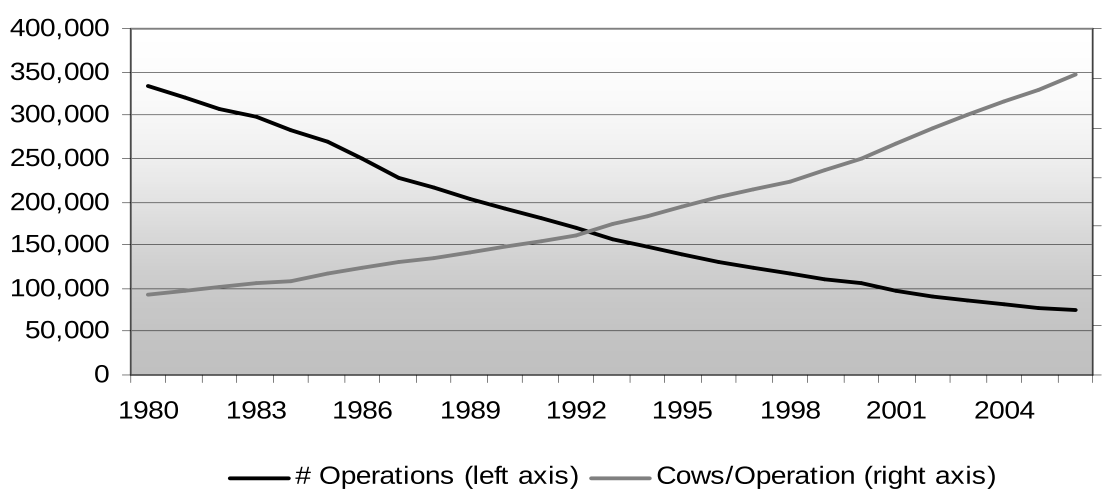


Source: http://www.nass.usda.gov/

Tracing supply-side developments more closely in last 30 years, we see that in 1980, there were 334,180 farms - or in industry's jargon "operations" – in business, with average farm size being just 32 cows. As Figure 2.5. below shows, number of operations has been dramatically reduced to just 75,190 in 2006, with farm size increasing four times to 121.

Figure 5.

Number of U.S. Dairy Farms and Average Farm Size, 1980-2006

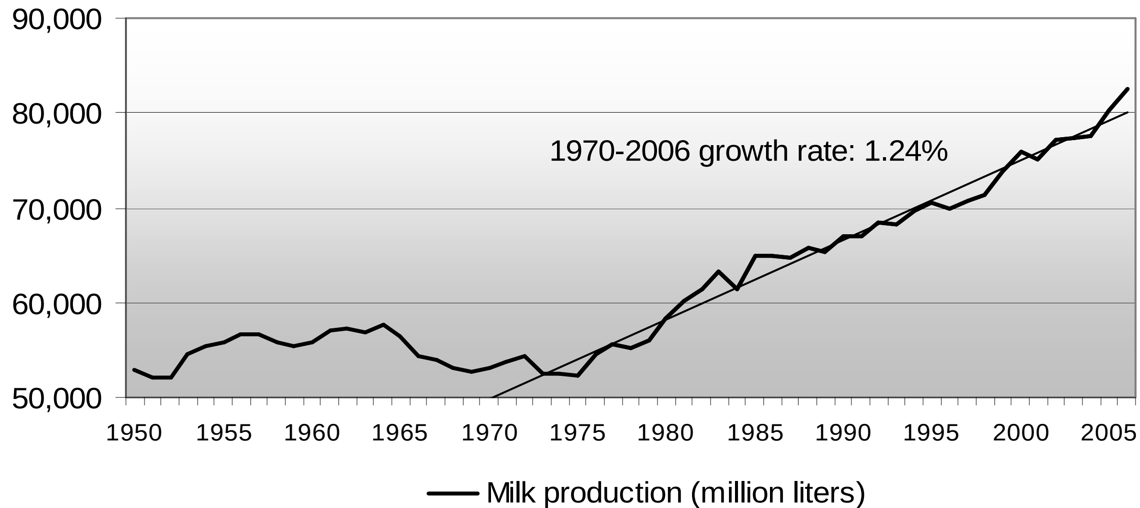


Source: [*http://www.nass.usda.gov/*](http://www.nass.usda.gov/)

While in the first half of this period, 1950-1975, milk production was fairly stabile, last two and a half decades show steady annual growth rate of 1.24% bringing total milk production from 52.3 million liters in 1975 to close over 82 million liters in 2006.

Figure 2.6.

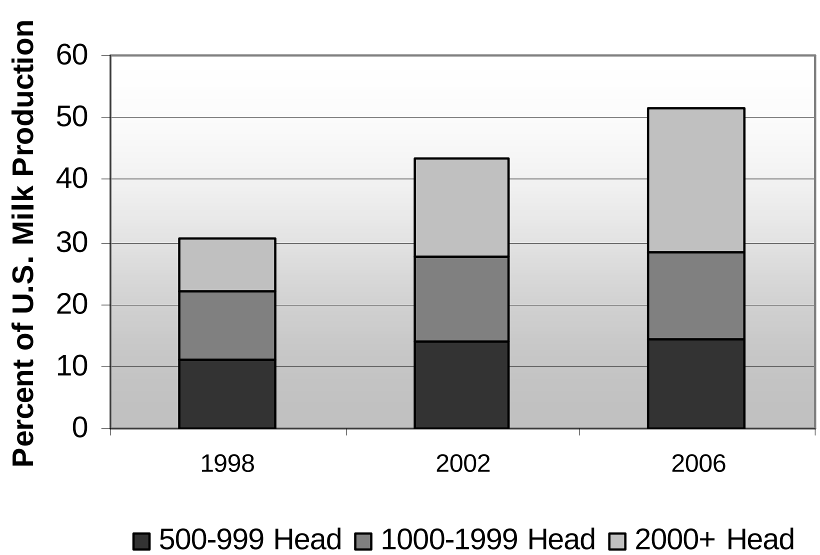
U.S. Milk Production, 1950-2006



Source: [*http://www.nass.usda.gov/*](http://www.nass.usda.gov/)

Figure 2.7.

Importance of Large Farms in U.S. Milk Production



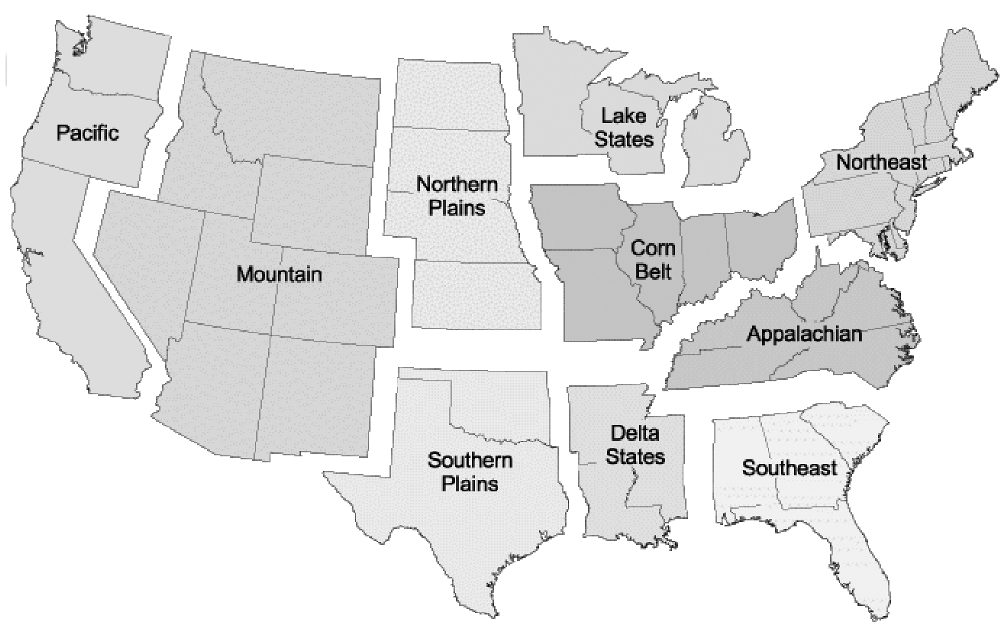
Source: http://www.nass.usda.gov/

Technological innovation fostered two principal shifts. First, the rise in importance of large farms (500+ cows) shown in Figure 2.7., which have seen their share of production grow from 30.5% in 1998 to 51.6% in 2006, even though they still constituted only 4.1 percent of total number of farms in 2006. Especially conspicuous is the rise of importance of very large farms, with 2000+ cows. Ten years ago, they accounted for less then 10 percent of overall milk production, while their share in 2006 was fully 23.4 percent.

Second trend is regional shifts of production. USDA (United States Department of Agriculture) divides USA into 10 production regions for the purpose of their analysis. Traditional milk producing areas are Lake States and Corn Belt.

Map 2.1.

USDA Agricultural Production Regions



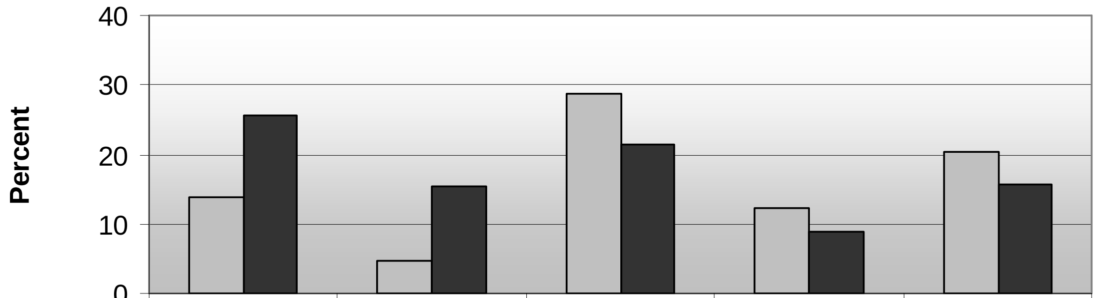
Source: Reproduced from Blayney, D. (2002): The Changing Landscape of U.S. Milk Production, USDA.

While traditional producers regions have gained in terms of share of operations, that, in fact, turns out to be consequence of lagging behind new areas – California, and

Washington State in Pacific region and Idaho and Colorado in Mountain region. Those regions show amazing increase in farm size, and correspondingly, significantly advancing shares of milk production.

Figure 2.8.

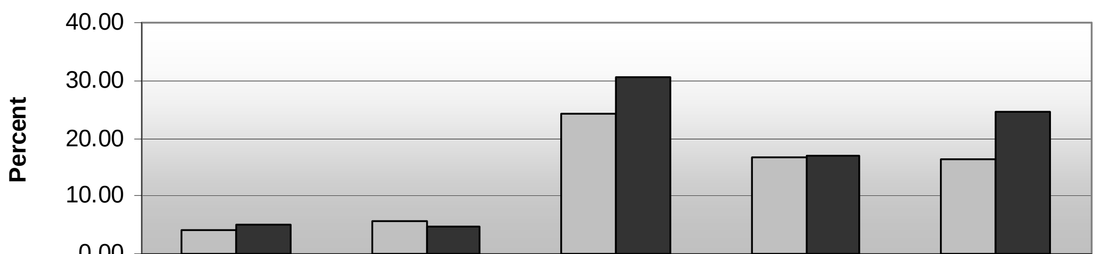
Regional Share of U.S. Milk Production, Major Regions, 1980 and 2006



	Pacific	Mountain	Lake States	Corn Belt	Northeast
1980	13.78	4.77	28.73	12.37	20.36
2006	25.60	15.30	21.38	8.86	15.57

Figure 2.9.

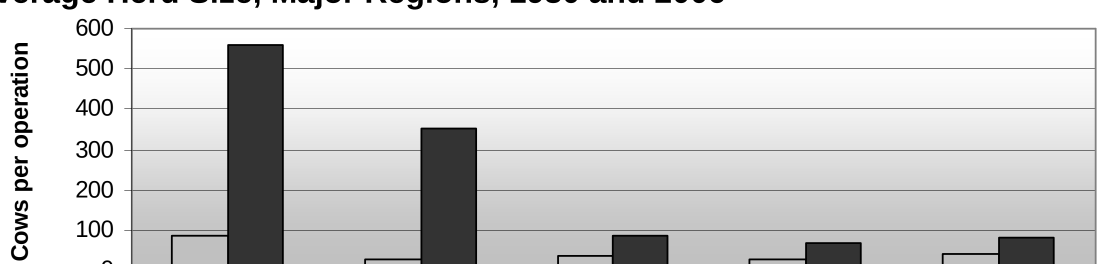
Percent of U.S. Dairy Farms, Major Regions, 1980 and 2006



	Pacific	Mountain	Lake States	Corn Belt	Northeast
1980	4.19	5.66	24.39	16.58	16.29
2006	5.07	4.78	30.61	17.03	24.62

Figure 2.10.

Average Herd Size, Major Regions, 1980 and 2006



	Pacific	Mountain	Lake States	Corn Belt	Northeast
1980	85	25	38	26	40
2006	560	352	88	67	81

Source for Figures 2.8-2.10: http://www.nass.usda.gov/

Should we expect these two trends to continue? One clue might come from "Agricultural Resource Management Survey" (ARMS), conducted in 2005. One of the questions in that survey was "How many more years do you expect this operation to continue producing mik?". Respondents were given choice between less than 1 year, 1 year, 2-5 years, 6-10 years, 11-19 years and 20 or more years. Following table shows that we should expect to see further decrease in number of operations by 15% in the period 2005-2010, accompanied with increase in average farm size.

Table 2.1.

Prospective Exit by Dairy Farms

		Percent of operations ending production	
Herd size	Sample observations	Within 5 years	Within 10 years
1-49	164	35.5	69.5
50-99	289	26.1	48.2
100-199	347	18.5	43.1
200-499	336	10.3	29.3
500-999	179	8.2	20.7
>999	147	7.4	22.0

Source: Agricultural Resource Management Survey (ARMS), 2005 Table reproduced from MacDonald, J. et al. (2007): Profits, Costs, and the Changing Structure of Dairy Farming, ERS Economic Research Report Number 47, USDA.

2.3. US Dairy Policy

USA dairy policy can be characterized as having two primary objectives: (i) to assure appropriate "standard of living" for dairy farmers, and (ii) to provide counter-cyclical stabilization of markets and assure orderly supply of milk. These two goals are embodied in two separated programs – Milk Price Support Program (MPSP), and Federal Milk Marketing Orders (FMMO).

Milk Price Support Program is basically intervention purchase program whereby federal government seeks to set effective price floor for milk in order to stabilize markets and provide sufficient living wage for dairy farmers. Originally, MPSP pricing had the goal of preserving ‘parity’, i.e. purchasing power of income farmer gets from one unit of milk. The price of manufacturing use milk has been supported continuously since passage of the Agricultural Act of 1949. This Act required the Secretary of Agriculture to support prices received by dairy farmers for manufacturing use milk at between 75 percent and 90 percent of parity. Here, parity price is defined as that price of milk that gives the farmer the same purchasing power as in the base period, which was 1910-1914. Using assumed yields and manufacturing costs, the support price for manufacturing use milk was converted into a support price per pound of cheddar cheese, butter and nonfat dry milk. That program is implemented through US Department of Agriculture’s Commodity Credit Corporation (CCC). CCC issues a standing offer to purchase unlimited quantities of butter, nonfat dry milk, and cheddar cheese at announced prices to keep the price of manufacturing use milk from falling below the support level. The assumption was that if cheese, butter and nonfat dry milk plants received these prices, then they would be able to pay dairy farmers at least the support price for their milk.

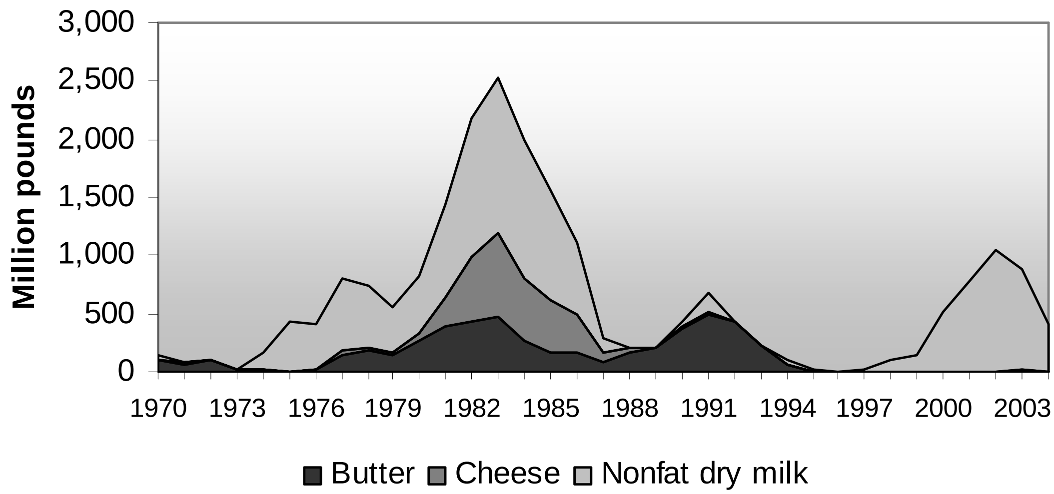
Market clearing real price of milk was falling since technological innovations and induced productivity increases were shifting milk supply curve to the right. Attempts to protect parity pushed the price above market clearing level, causing surplus production and stockpiling of government purchased dairy products. Inflation during the 1970s resulted in the support price increasing from $4.28 per hundredweight[3] on October 1,1970 to $13.10 per hundredweight on October 1,1980. Dairy farmers responded by increasing milk production far beyond commercial use. Surplus dairy products purchased by the CCC under the support program approached 10% percent of farm marketings and associated government costs approached $2 billion annually.

Policy mistakes of that time can best be seen in Figure 2.11. that shows how great were stocks of products CCC removed from the market.

[3] Hundredweight=100lbs, or 45.36kg.

Figure 2.11.

U.S. Government Stocks of Dairy Products



Source: NASS, "Cold Storage", from 2005. Dairy Yearbook.

This surplus situation resulted in a major change in the support program. The Agriculture and Food Act of 1981 abandoned the parity approach to support price, and tied it instead to to both the level of CCC purchases and associated net government cost of the program. Under these provisions and subsequent amendments, the support price was gradually lowered. The Food, Agriculture, Conversation and Trade Act of 1990 set a minimum $10.10 per hundredweight support price through 1995. The Federal Agricultural Improvement and Reform Act of 1996 increased the support price to $10.35 per hundredweight for 1996, with subsequent reductions of $0.15 each January 1 to $9.90. In recent years, market price of milk has been much higher than support price. Seeking to provide counter-cyclical support without inducing new wave of misplaced investments in excess capacity, federal government has enacted new instrument called "Milk Income Loss Contract" (MILC). It offers to farmers to partially reimburse their forgone income when price of milk falls below what is considered a long-run equilibrium price. Payments to individual producer are limited up to a certain sum, so this is also, at least in part, instrument of social policy since smaller farmers are favored against big producers. There have been no CCC purchases of surplus dairy products since 2004.

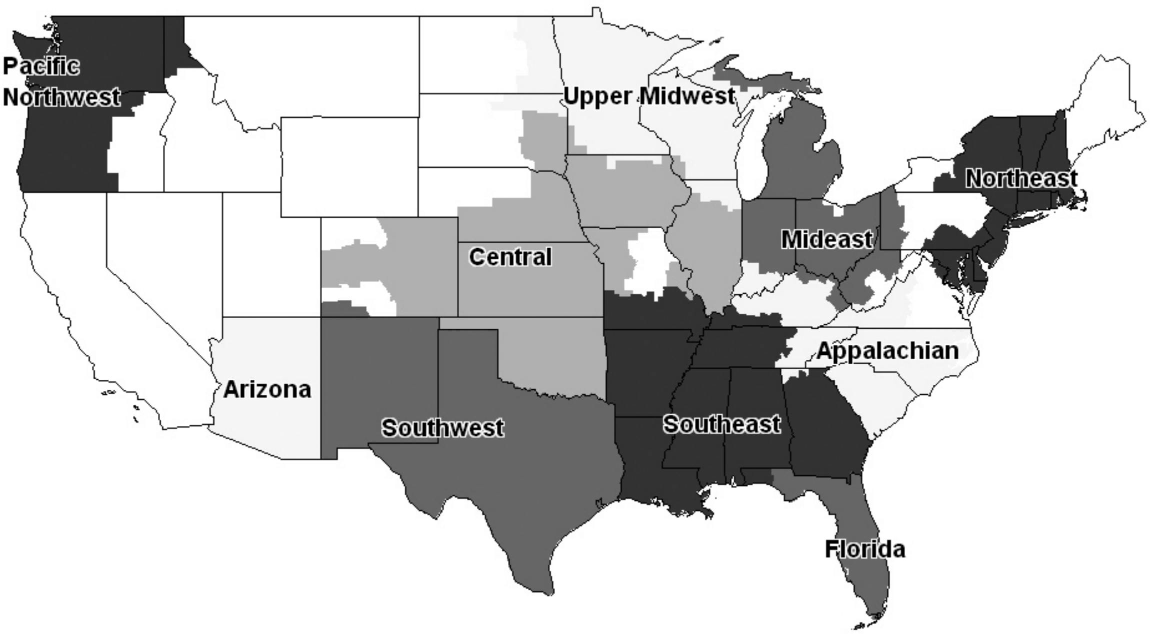
Second pillar of US dairy policy are Federal Milk Marketing Orders (FMMOs). FMMOs are set of regulations that address the specific nature of milk as a commodity. Milk is a “flow commodity”, which means that it is produced every day, and that it must move quickly to market. Fresh milk cannot be stored without processing, which implies that day-to-day milk supply is not balanced with demand. Furthermore, such nature of production would mean that in absence of any regulations, milk processing plant owners would have immense power over local dairy farmers. To mitigate the potential adverse effects of this setting, Federal orders have been authorized by Agricultural Marketing Agreement Act of 1937. They are not mandated – they must be approved by majority of producers in certain area in order to become effective.

Under FMMO, USA is divided into 10 regions, and each farmer in one region gets the same uniform price for his milk – founded on basic attributes of milk he delivered: proteins, butterfat, milk solids, somatic cells count and location within that region. Under FMMO, national minimum price for four classes of milk is announced, where classes correspond to end-product utilization of milk (beverage, soft manufactured products, cheese, and butter and dry milk products). Those minimum prices under ‘classified pricing’ system *are not* in any direct way related to support prices, but are merely calculation of national average of market-clearing prices for final products based on milk.

To see what is achieved by this, we must recall that the price of milk individual producer (farmer) receives is based solely on the physical attributes of his milk – not the type of final product his milk is directed into. In such way, prices are evened out within the region through a process called ‘pooling’, and orderly supply of milk is insured that greatly reduces transaction costs. Map of USA provided below shows ten regions formed under FMMO system. It is important to notice that California, which is major milk producing area – is not part of this system. As was said before, Federal orders are not mandated, and California’s farmers have decided to form a system of their own under California State legislation.

Map 2.2.

U.S. Regions under Federal Milk Marketing Order System: January 1, 2001.

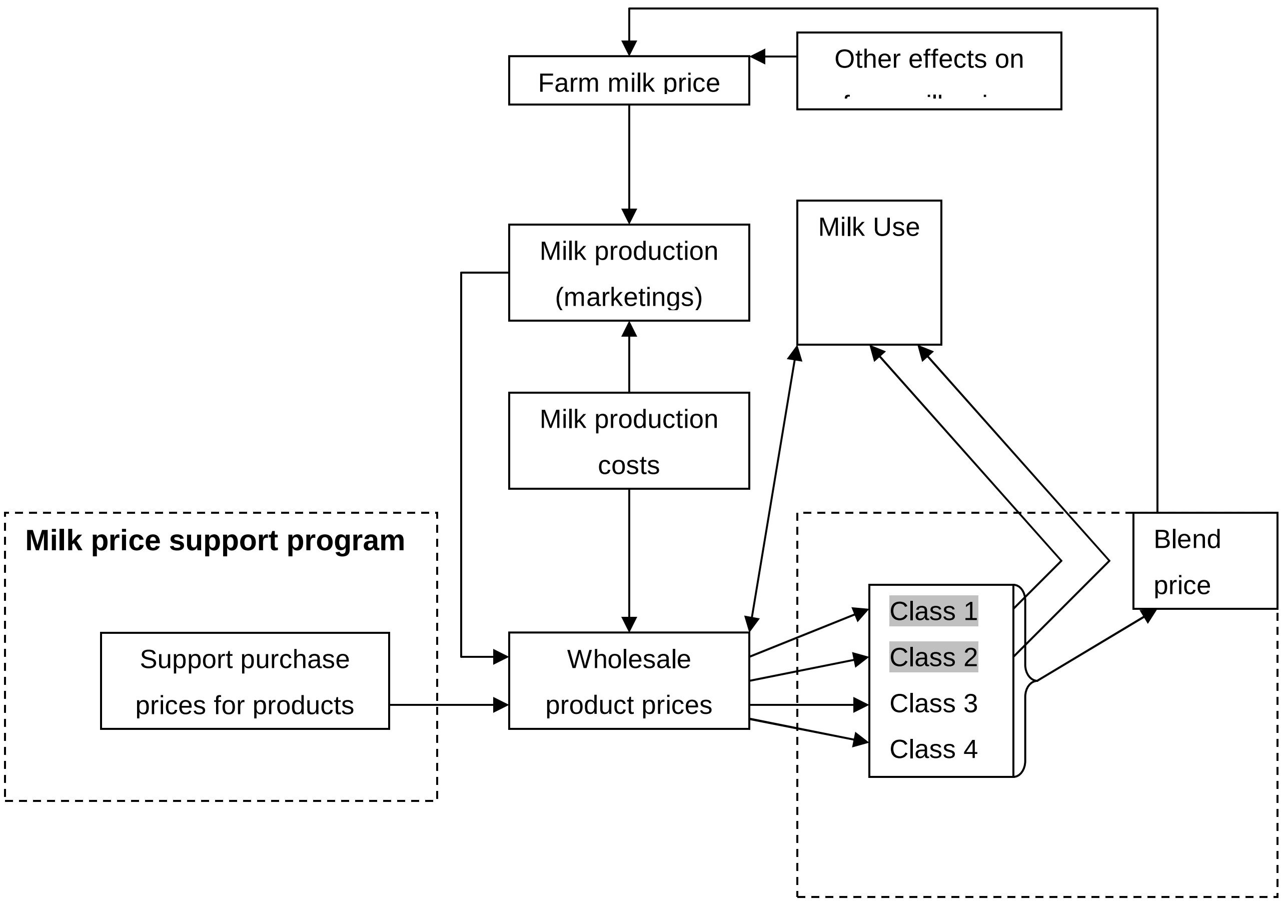


Source: Jesse, E. and Bob Cropp (2004): Basic Milk Pricing Concepts for Dairy Farmers. University of Wisconsin-Extension.

Figure 2.12. depicts the impact of these two programs on milk price. To summarize, federal milk marketing orders deal mostly with removing very short-run oscillation in prices. Longer run counter-cyclical and living wage support is provided by milk price support system.

Figure 2.12.

Linkages between the Milk Price Support Program and the Federal Milk Marketing Orders



Source: Reproduced from Manchester, A. and Don P. Blayney (2001): Milk Pricing in the United States, Agriculture Information Bulletin No. 761, ERS, USDA.

2.4. U.S. and EU Dairy Policy Compared

While U.S. diary policy may seem to an average American economist as the bastion of government meddling with the markets, when compared with EU policy, it suddenly turns reminiscent of Smithsonian lassiez-faire ideal. One web site has recently reported on Czech Republic's dairy industry as "…greater efficiencies and improved breeding practices by farmers are thought to be at the centre of the problem…" The 'problem' is in fact the collision of technological innovation and cost-minimizing farm management practices that are increasing taking place after accession of that state to EU, with hyper-regulated quota system that is Europe's take on how to stabilize internal market.

EU dairy policy can best be understood as a series of attempt to patch the distortions created by previous measure, although attempts are always presented as one step further to efficient markets. For the purpose of this comparative analysis only brief outline of EU dairy policy is given. First, as in US, there exists an intervention price instrument, effectively creating a price floor for milk. Basic economic analysis informs us that any such intervention price, in absence of some accompanying constraint on producers, is going to induce persistent oversupply of the product regulated. That happened both in US and in EU in early 1980s. Their approach to solving the problem was fundamentally different. While US government decided to lower support prices, and pay for a massive milk termination program whereby entire herds were bought out from farmers and slaughtered, in 1984 EU introduced quotas on both individual farmers and member states, with fines for production over the limits. One reason behind the policy difference might be that US never explicitly set "preserving family farming" as the policy goal, and consolidation of the industry was never hindered. We would be making an erroneous conclusion if we are to state that what EU was creating was purely market inefficiency, bringing about Pareto inferior allocation. Active rural areas were always part of European cultural heritage, and this policy can, if only in part, be understood as an outcome of European average consumer's preferences. However, other economic reasons were surely kept in mind – higher unemployment rate in EU, lower labor mobility than in US, and problematic communist "iron curtain", which was showing first signs of collapse. To accompany quotas, trade instruments are used: export subsidies and import tariffs. Third pillar of EU dairy policy are direct payments to farmers. As intervention price has been reduced in the last three years, “dairy premiums” were paid to milk producers to ease the transition to more competitive market. As of 2007, dairy premiums gave way to “Single Payment Scheme” – in a nutshell, an attempt to fully decouple support given to farmers from the level of their production, and in such way to discontinue inducing distortions of supply incentives.

It’s easy to get lost in the details of convoluted parallel worlds of European and US dairy policies, but the principal difference stands to be the target industry structure. In Europe, under the premise of “family farming”, large scale operations are effectively discriminated against. In USA, size of the farms was never explicit policy goal – and stabilization of internal market is clearly separated from “standard of living” support instruments, where first is embodied by Federal Milk Marketing Orders, and second by support prices for butter, non-fat dry milk and American cheese.

Quantitative comparisons reveal staggering differences. 450 million strong population of EU-25 is one half higher than US which counts 300 million people. However, while EU still has over 1.6 million dairy farmers, a number that can only kindle memories of late 1950’s when US had about 1.1 million farmers. Today USA has just under 80,000 farmers. Annual yield in USA has in 2006 surpassed the threshold of 9000 liters per cow, a figure that stands far above even the most advanced of states in EU. With EU-25 average of 6000 liters, Europe is not less than 20 years behind America, and less developed European states have yield (i.e. Latvia and Poland – 4000 liters) that USA had in 1967, fully 40 years ago.

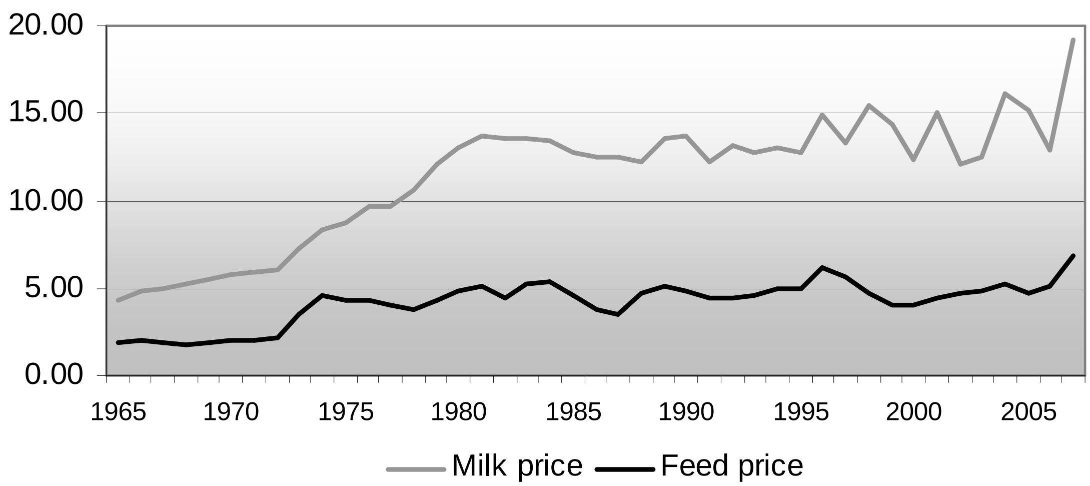
2.5. Economic Environment of Dairy Sector

I wrap up this overview chapter by presenting fundamental trends in prices of relevance to dairy industry. There are three set of prices which are always analyzed when it comes to milk production. First one, of course, is the price of the milk itself. However, that does not tell us much if we do not put it in comparisons to prices of inputs used in production of milk. Therefore, second set of prices includes prices of feed crops: corn, soybeans, and alfalfa hay. These are usually not viewed separately but they are rather combined to estimate "feed price". Namely, farmers mix basic crops to provide their herd with balanced nutrition containing all necessary elements. USDA uses formula whereby it assumes that feed mix contains 51% of corn, 41% of alfalfa hay and 8% of soybeans. That measure implicitly assumes zero elasticity of substitution between included components and therefore biases supply response elasticity with respect to feed price upwards. However, to follow industry standards, we use the same feed variable in this analysis. Third price of interest is the slaughter price of dairy cow. To comprehend the role this variable plays, we must understand the basic decision choice of a farmer. In any particular point he can decide to keep the herd size unchanged, and derive his profit from proceeds for milk delivered, or he can decide to forfeit some future milk produced in favor of delivering fraction of his herd to slaughterhouse. That decision depends on both prices of milk and slaughter price of dairy cows.

Figures 2.13 and 2.14 show nominal and real prices of milk, feed, and slaughter price for cows in the period 1965-2006. Most important trend is the long-run trend of fall in real price of all three variables. That is the consequence of technological innovations in face of inelastic demand for milk, meet and agricultural products.

Figure 2.13.

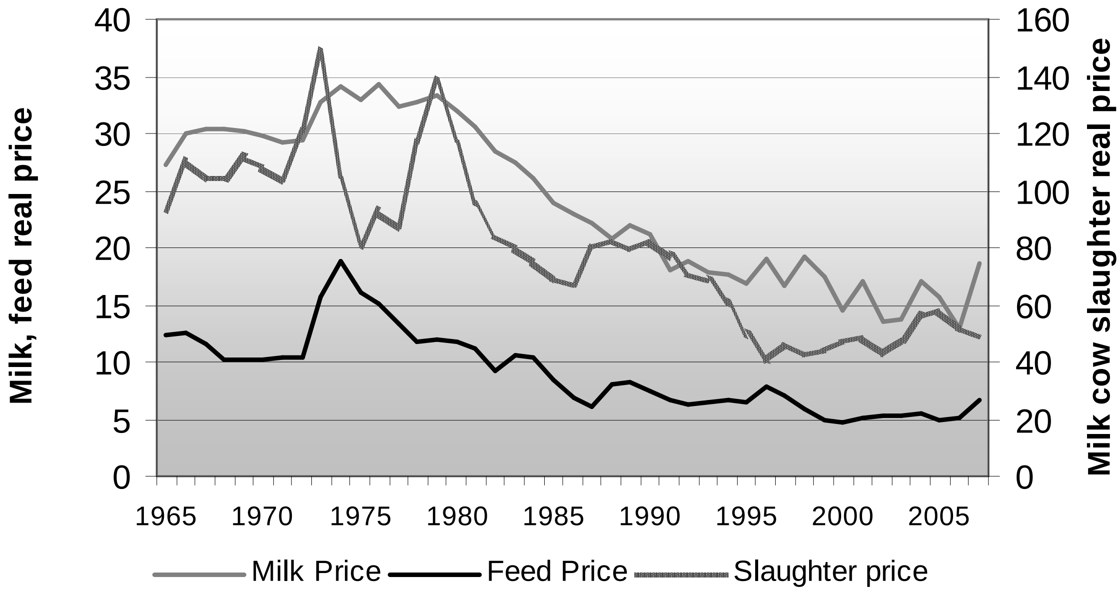
Nominal price of Milk and Feed, USD/cwt



Source: http://www.nass.usda.gov/

Figure 2.14.

Real Price of Milk, Feed and Dairy Cow Slaughter, 2007 USD/cwt

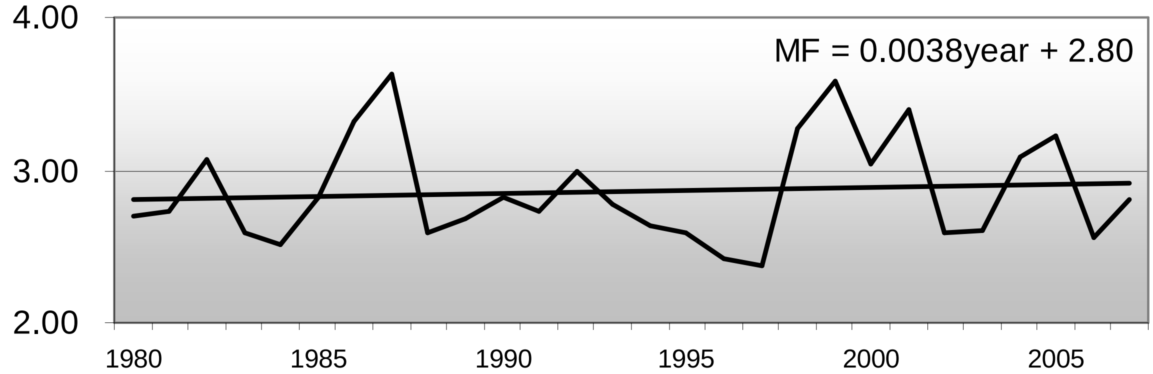


Source: http://www.nass.usda.gov/

Convenient way to capture economic opportunities farmers are facing is to put milk price against both input prices and opportunity costs of milk production, i.e. slaughter price. That gives us milk-feed price ratio, and milk-slaughter price ratio. Higher milk-feed price ratio, all other things equal, implies that farmers can earn more profit from their production. If a sufficiently high milk-feed price ratio is sustained over long enough period, that will bring more producers into the industry, raising demand for feed thus increasing price for it, and raising supply of milk, thus reducing it's price. Both impacts work to reduce milk-feed price ratio to it's long-run equilibrium. Figure 15 shows that long-run equilibrium milk-feed price ratio in the last 25 years was 2.8.

Figure 2.15.

Milk-Feed Price Ratio



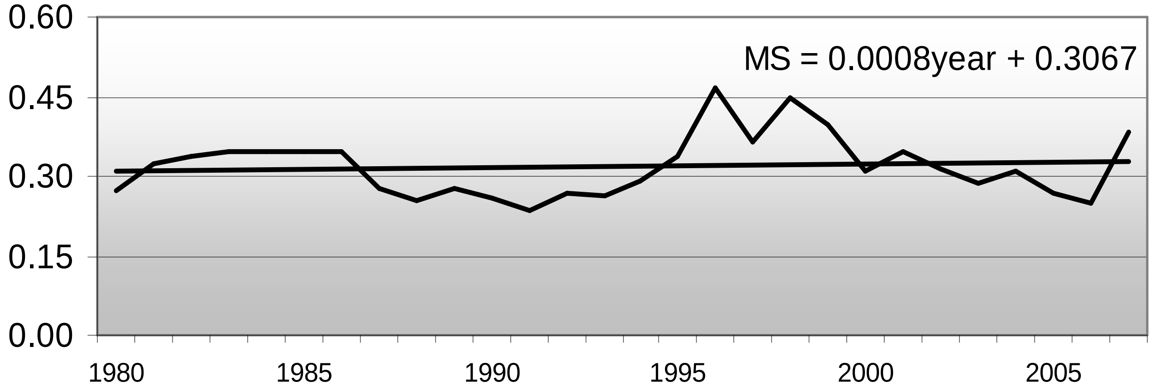
Source: *http://www.nass.usda.gov/*

Interesting question to ask is how technological innovation impacts milk-feed price ratio in the long run. That scenario is generated by two main trends. First, technological innovation in milk production sector would likely decrease average feed input requirement per unit of milk. If so, then long-run equilibrium milk-feed should be expected to be lower than today. However, we must recall that technological innovation is present in other sectors as well. In particular, ability to produce transportation fuel from agricultural crops introduces additional demand for both milk production inputs and the land on which those crops are produced.

One aspect of farmer's opportunity costs are captured by milk-slaughter price ratio. When this ratio falls, then farmers have higher incentives to sell their cows to slaughterhouse. When it goes up, we expect to see higher retention rates and expansion of herd size, or at least reduction in the rate herd is being shrunk due to technological change. Long-run average milk-slaughter price ratio in the last 25 years was 0.3.

Figure 2.16.

Milk-Slaughter Price Ratio

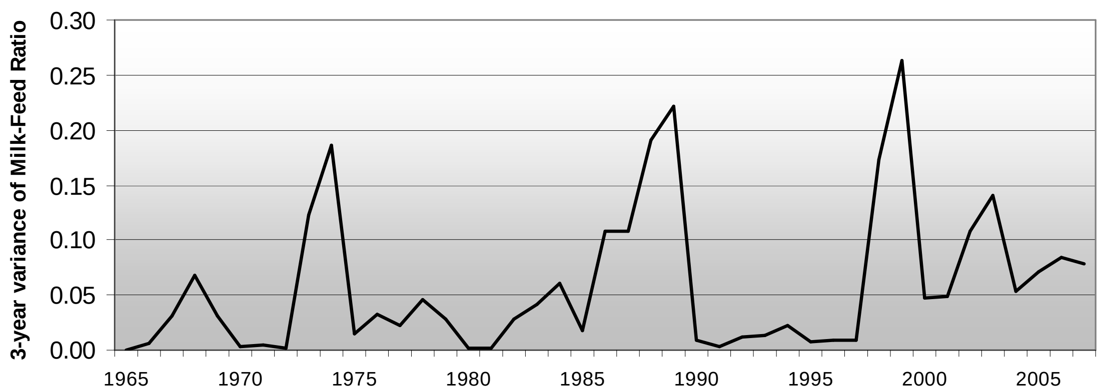


Source: http://www.nass.usda.gov/

Final thing we address is the increase in variability of both input and milk prices. Higher variability means higher risk for the producer, as past performance of the market becomes less reliable predictor of what is to come. To get a sense of riskiness milk sector is facing, we calculate two measures. First, as the primary risk variable we use milk-feed price ratio 3-year moving variance. Since milk-feed price ratio measures only relative prices, increase in nominal prices over time do not affect this risk measure. Secondly, we want to get a grasp at what causes higher risk – milk or feed. For that purpose we calculate 3-year moving standard deviation of milk price, and divide it with 3-year moving mean of milk price. Two points emerge. First, dairy sector has experience three high-risk periods, with first two being driven by feed-costs, and third one by milk price. Second, riskiness of the environment has shifted to new and higher post-peak level since 2000.

Figure 2.17.

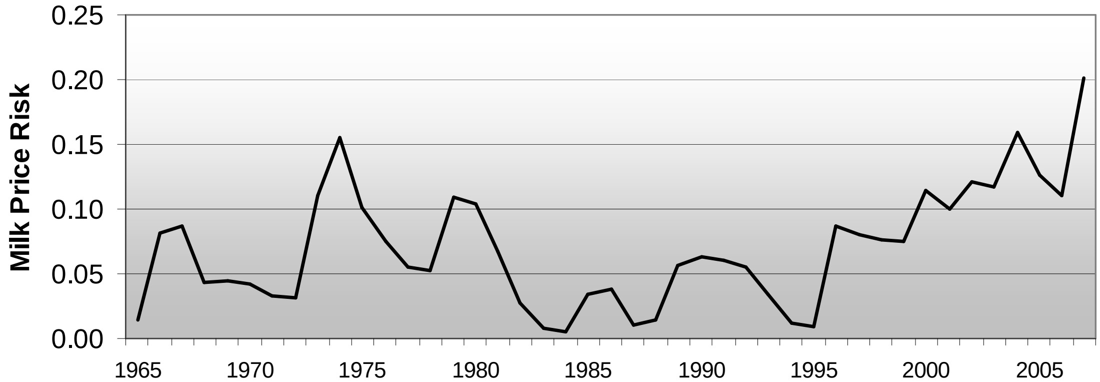
Milk-Feed Price Ratio Risk



Milk-Feed Price Ratio Risk is calculated as a 3-year moving variance of Milk-Feed Price Ratio.

Figure 2.18.

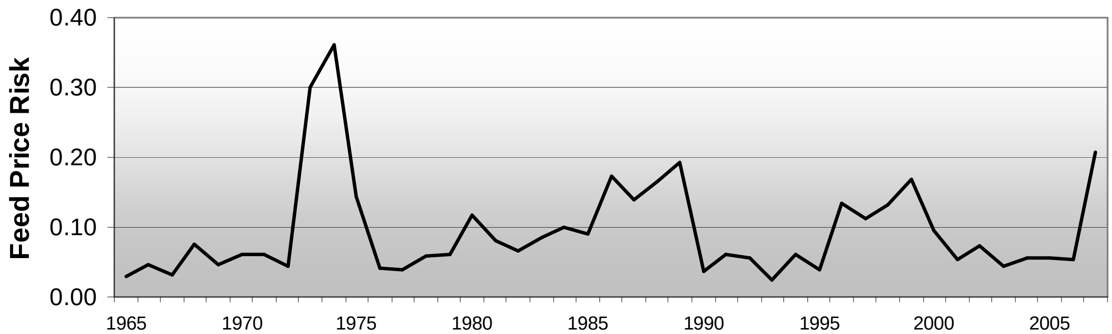
Milk Price Risk



Milk Price Risk is calculated as the 3-year moving standardad deviation of milk price divided by the 3-year moving mean price of milk.

Figure 2.19.

Feed Price Risk



Feed Price Risk is calculated as the 3-year moving standardad deviation of feed price divided by the 3-year moving mean price of feed.

This completes the overview of US dairy sector, and the economic and policy environment in which it operates. In the next section we employ tools of economic analysis to build framework for analyzing the dairy sector.

3. Econometric model of U.S. milk production

Above described significant structural changes occurring in the U.S. dairy industry, together with paucity of recent econometric models of U.S. dairy supply, justify our choice of three main objectives of this study: (i) quantify the current supply structure of U.S. dairy industry, (ii) gain insight into impacts of technological changes that have occurred over the last 25 years, (ii) using these, generate forecasts of long-run milk supply response to price changes and possible future technological advancements. We first summarize recent published articles on this topic.

3.1. Literature Review

Huy, B. et al (1988) use profit function approach based on duality theory to analyze production characteristics of represenatitive dairy farms across U.S. milk production regions. They model structural characteristics via restricted translog profit function and employ iterative seemingly unrelated regression to solve their model. Authors find that Norhteastern producers have lagged behind California and Texas in terms of improvement in efficiency. This study foreshadowed massive regional shifts that occurred since that paper was published in later 1980s.

Chavas, J.P. et al. (1990) estimate regional model of U.S. milk supply. Authors use pooled time series-cross-section model specified as a flexible polynomial lag model and estimated by seemingly uncorrelated regression. They find that price elasticities of supply vary across regions, and conclude that dairy policy has impact on regional evolution of U.S. dairy production.

Yavuz et al. (1996) compare the importance of dairy policy, supply and demand factors for shifts in regional distribution of milk production. They use spatial equilibrium analysis where they model U.S. milk production regions as spatially separated markets. They find that supply factors had by far the strongest impact on the regional distribution of milk production over the period 1970-1991.

USDA Agricultural Market Service (USDA AMS, 2007) maintains dynamic econometric model of dairy industry to support its economic analysis and forecast responsibilities. Model is more comprehensive than published articles in the sense that it addresses not just supply side, but also detailed analysis of demand for dairy products. Where all research papers calculate long-run elasticities based on imposed prices, USDA model solves for market clearing prices for dairy products, fluid and farm milk. However, we find their model inadequate since it fails to show statistically significant difference between short-run and long-run milk supply price responsiveness due to simple linear structure.

Chavas and Klemme (1986) model U.S. milk production address herd dynamics more specifically. They incorporate biological information and influences of economic environment on culling rates and heifer replacement decisions. They manage to show that long-run elasticities are much higher than short-term price elasticities, thus gaining insight into dynamics of milk supply adjustments over time. Since their model allows us to trace the impact of technological changes on long-run supply response, we build upon their approach in our study.

3.2. A Brief Primer on Cow Biology and Herd Management

It will be expedient to begin discussion on modeling dairy herd size by brief overview of dairy cow biology. Reproduction cycle for cows is 14 months, out of which 9 months is the length of pregnancy, and 5 months is the current industry average period between freshening (giving birth to a calf) and start of the next pregnancy. Cows produce milk from the moment they give birth to about two months prior to next freshening, when they are withdrawn from the milking herd, and left to rest before the forthcoming delivery. Newborn calves take on average 9 months to reach the weight of 500 pounds. USDA considers as replacement heifers all cows that weigh 500lbs or more, and have not calved yet. Heifers are impregnated at 15 months of age, and give birth just about when they reach 2 years of age. From that timeline, logical definition of the replacement heifer follows: for the purposes of this model, a replacement heifers in period *t* is a female calve of at least one year of age at the beginning of the period, which is expected to enter the herd before the end of the period. Upon their first calving, replacement heifers are accounted as dairy cows and are part of dairy herd. We define as a dairy cow a female bovine animal that have calved at least once, and is held in herd for primary purpose of milk production.

While maximum biological age for a cow is about 20 years, intensive milking and frequent calving make cows susceptible to various diseases. While those health problems are mostly treatable, they tend to make salvage value of the cow fall below the present value of the future earnings that such cow could produce, and such cow is promptly sent to slaughterhouse. Other reason why cows get removed from the herd is genetic progress which makes younger cows more productive than the older ones. When enough replacement heifers are available, older cows are likely to be removed more aggressively.

It is now clear from this short overview that dairy herd size and changes in size and structure are determined primarily by the culling and cow replacement decisions. Hence all economic actions taken in pursuing profit maximization should be captured by decisions with respect to (i) which cows currently in the dairy herd should be removed from the herd and sold for slaughter, and (ii) how many calves should be grown into replacement heifers and subsequently added to the herd.

3.3. Model Equations

Similar to the structure of the national model of U.S. milk supply by the USDA (USDA, 2007), we model total U.S. milk production as the product of the number of milk cows in U.S. dairy herd (COW), and average yield per cow (YLD):

$$MILK_t = COW_t \times YLD_t \qquad (1)$$

The understanding of biological and economic decisions governing the dairy herd dynamics can best be exploited by addressing issues of yield and herd size in two separate stochastic equations. Total U.S. milk production is then predicted by the identity equation.

We assume that heifers enter the herd when they are 2 years old, and that maximum productive lifetime of a dairy cow is 9 years in the herd for a total of 11 years. We assume that each year herd manager makes a decision how many cows of each of the 9 productive age classes he will keep in the herd for another year. We model those decisions by survival rates $S_{t,i}$ given by formula (2), that is probability that in year *t* cow in *i*-th productive age class will survive one more year.

$$S_{t,i} = \frac{1}{1+e^{Z_{t,i}\beta}}, \quad (i = 1,...,9) \quad (\text{t=1,...,T}) \qquad (2)$$

In the above equation, for each age class, vector of explanatory variables $Z_{t,i}$ reflects the state of technology in year *t*, economic conditions, and age of that class at the time of selection decision. β is the associated coefficient vector we seek to estimate.

The number of cows in *i*-th productive age class is determined by the product of number of replacement heifers *i* years ago and retention rate, which is the product of survival rates in the past *i* selection decisions. Retention rates[4] of each productive class *i* in year *t* is mathematically represented by equation (3)

$$R_{ti} = \prod_{j=1}^{i} S_{t-j,i-j} \qquad (3)$$

Total herd size is modeled in equation (4) as the sum of cows in each of nine productive age classes with the addition of uncorrelated zero-mean stochastic errors.

$$COW_t = \sum_{i=1}^{9} COW_{ti} + e_t = \sum_{i=1}^{9} HEF_{t-i} \times R_{ti} + e_t \qquad (4)$$

It will help us later to define culling rate k_{ti} as the fraction of productive age class *i* removed from the herd in year *t*.

$$k_{ti} = 1 - S_{t,i} \qquad (5)$$

Complete cow equation is given in the equation (6).

$$COW_t = \sum_{i=1}^{9} HEF_{t-i} \left[\prod_{j=1}^{i} \left(\frac{1}{1+e^{Z_{t-j,i-j}\beta}} \right) \right] + e_t \qquad (6)$$

While the above model of dairy herd size and composition, in conjunction with yield equation which we describe below, suffices for short-run forecast of milk production, we need to explicitly model cow replacement decisions if we want to understand medium- and long-run behavior of U.S. dairy supply. As stated previously, replacement decisions describe the selection of female calves to become replacement heifers. We model replacement heifers via equation (8).

[4] In event history analysis terminology, what is here termed survival rate would correspond to 1-hazard rate, and what we refer to as retention rate is called survivor function.

$$\Gamma_t = \frac{1}{1+e^{W_t\beta}} \qquad (7)$$

$$HEF_t = \frac{1}{2}\left\{\left(COW_{t-2} + HEF_{t-2}\right)\times\left[\frac{1}{1+e^{W_t\beta}}\right]\right\} + e_t \qquad (8)$$

To arrive at this formula we make several important assumptions. First, counterpart of retention rates in cow equation is the logistic function (7) that captures both the probability of successful calving, and surviving until the one year of age. Second, via parameter $\frac{1}{2}$ with which the formula starts, reproduction rate is limited to be no more than one half to reflect the fact that in absence of using sexed semen half of newborn calves will be male animals not suitable for cow replacements. Finally, we depart from Chavas and Klemme (1986) and follow Schmitz (1997) in modeling pool of fertile animals that can produce offspring to include not just dairy cows in the period *t-2*, but also replacement heifers at that time.

Model is completed by estimation of yield equation (9) which takes simple linear form.

$$YLD_t = X_t\beta + e_t \qquad (9)$$

3.3. Explanatory variables

Vectors of explanatory variables for all three equations are listed by in the table (3.1.).

In each equation there are three sets of explanatory variables: (i) variables that capture the state of technology and technological and genetic progress, herd structure and adjustment dynamics; (ii) variables that describe economic environment; (iii) dummy variables that account for impacts of government policies.

Table 3.1. Explanatory variables by category

Dependent variable	Explanatory variables: Symbol	Categories: Technology, Herd Structure, Dynamics	Prices		Government Policy
COW_t	$Z_{t-j,i-j}$	ONE	MP_{t-j}	$MP_{t-j} \times AGE$	$Dum84 = \begin{cases} 1, & \text{if } t-i+j=1985 \\ 0, & \text{otherwise} \end{cases}$
	$i=1,..,9$	$AGE = i-j+3$	FP_{t-j}	$FP_{t-j} \times AGE$	
	$\forall i, j=1,...,i$	$\dfrac{HEF_{t-j}}{COW_{t-j}}\left(AGE-3\right)$	SP_{t-j}	$SP_{t-j} \times AGE$	$Dum86 = \begin{cases} 1, & \text{if } t-i+j=1987 \text{ or } 1988 \\ 0, & \text{otherwise} \end{cases}$
HEF_t	W_t	ONE	MP_{t-1}	MP_{t-3}	$Dum84 = \begin{cases} 1, & \text{if } t=1985 \text{ or } 1986 \\ 0, & \text{otherwise} \end{cases}$
		$T = t-1974$	FP_{t-1}	FP_{t-3}	
			SP_{t-1}	SP_{t-3}	$Dum86 = \begin{cases} 1, & \text{if } t=1987 \text{ or } 1988 \\ 0, & \text{otherwise} \end{cases}$
YLD_t	X_t	ONE	MP_t	MP_{t-1}	$Dum84 = \begin{cases} 1, & \text{if } t=1984 \\ 0, & \text{otherwise} \end{cases}$
		$T = t-1974$	FP_t	FP_{t-1}	
		YLD_{t-1}			

Technological progress is represented explicitly in heifers equation by trend variable. Recall that in heifer equation (8) that variable enters in the exponent of logistic function. This modeling approach allows us to model the heifer management as possibly getting more effective over time. This allows that, due to better technology, attempts to fertilize cow be more successful, calves death rate can be reducing, and more calves selected to be grown into replacement heifers actually complete the process without severe health problems that would induce involuntary culling. Trend variable in this equation reflects technological change indirectly as well. With more intensive milk production, and genetic selection that favors higher yield over more robust immunity to health problems, profitable life cycle of a cow will likely reduce. One of the consequences will be that more calves will be selected for replacement, and that effect will also be captured by this trend variable.

In yield equation (8), trend variable reflects primarily genetic improvements of dairy cows. Indeed, that process dominates by far all other variables that contribute to explaining the variation in yield. Technological progress and herd dynamics are captured in cows equation (6) by two variables: (i) *AGE*, which is age of the dairy cow for which culling decision is to be made, allows that survival rates differ across 9 productive age classes; (ii) replacement ratio – ratio of replacement heifers to dairy cows. Higher replacement ratio means that more heifers are ready to enter the herd, and consequently, more of the older, and less productive cows, can be removed from the herd without reducing the herd size. It is reasonable to assume that effect of higher replacement ratio will be different for different productive age classes, so the variable that captures this effect is the interaction of cow's age and replacement ratio, $\frac{HEF_{t-j}}{COW_{t-j}}(AGE-3)$. Following Chavas and Klemme (1986) we assume that higher heifer availability does not influence culling decision of cows that have just entered the herd in previous period.

To allow greater functional flexibility, we include free parameter ONE in logistic functions in both heifer and cows equation, as well as in yield equation. One can interpret the free parameter as average technology/productivity over the estimation period.

Technological progress is also reflected in the parameter $\frac{1}{2}$ in heifers equation. That number reflects the expected ratio of female to male calves immediately after calving, before any culling decision is made. With further technological progress and decline in price of sexed-semen, wider adoption of that technology is likely to push this parameter in the range of 0.7-0.8. While we fix this parameter when estimating the model, by increasing its magnitude in some simulated scenarios we are able to make a first pass at investigating the impact of sexed-semen adoption to price responsiveness of milk supply.

We include three set of prices that characterize economic environment of dairy sector: milk price MP_t, feed price FP_t and cow slaughter price SP_t. We use real prices, in contrast to Chavas and Klemme (1986) who in their model use milk/feed and slaughter/feed ratios as principal economic variables. Models based on price-ratios imply that proportional change in all three prices act as neutral inflation which has no impact on physical processes. That assumption cannot be justified when capital costs are significant. When capital investments in milk production are substantive, farmers must make operative profit on the last unit of milk produced in order to pay for the cost of capital employed. In such setting, proportional increases in prices of output and variable inputs must increase operative profit as well, and cow replacement and culling decisions will reflect that.

We assume that culling decisions are made in such fashion to equalize present value of future earnings from the cow with the current salvage value which is cow slaughter price. We assume adaptive expectations where future prices are expected to be equal to last observed price. In cow equation, prices are lagged up to nine periods. Given the assumed form of price expectations, proper interpretation of these lags is that past culling decisions, which are irreversible and depend only on past expectations, still influence the herd size and structure by determining the retention rate of each productive age class at the beginning of the current culling decision period.

Changes in economic environment will influence each productive age class differently. When production is more profitable, herd manager might decide to replace more of the older and less productive cows. The opposite holds as well, when prices make for less lucrative production, it will not be profit-maximizing to invest in more productive, but expensive, replacement heifers, and that might be reflected in higher retention rates of older cows. While intuition is here best developed by imagining that manager compares the present value of future earning of the cow with the market price of live replacement heifer, we need to point out that we model the U.S. dairy herd as one big representative herd in competitive market. That modeling decision implies that heifers are not traded, and can only be grown, which justifies the exclusion of live replacement heifer price as one of the economic variables in heifer equation. To capture the differentiated effect of price changes upon each productive age class, we use price-age interaction variables (i.e. $MP_{t-j} \times AGE$) in cow equation.

To understand how prices influence the number of replacement heifers, recall that it takes 1 year for female calve to grow into replacement heifer ready to freshen and enter the herd in the current period, and that a cow is pregnant for 9 months before giving birth to calf that is to become a replacement heifer. Relevant pool of dairy animals that could give birth to calves that will have grown to replacement heifers by period *t* is the number of cows and replacement heifers in period *t-2*. First decision that influences the number of replacement heifers today is how many of those cows are to be impregnated in period *t-2*, and how many are culled. Culling decisions in that period, given the assumed form of expectations, depend on prices observed in period *t-3.* Second decision of relevance is the share of female calves that are selected to be grown into replacement heifers. To capture the effect economics have on this decision we include prices in the period *t-1*.

While yield equation, having a simple linear structure, may seem most straightforward one, it is in fact the case that impact of prices on yield are theoretically most challenging to model. The reasons for that are the two opposing effects on yield that occur with any type of price changes. One of the most important day-to-day decisions of farm manager is the feeding regime. Feeding regime that maximizes yield will likely be put in place only in periods where production is very lucrative, i.e. price of milk increases, or price of feed decreases. However, in precisely those situations, shifts in desired herd size will take place, with managers likely seeking to enlarge their herds, while exit rate of small farmers decreases as some of them postpone retirement. Should there be scarcity of replacement heifers at that point, farmers will increase the retention rate of older cows, not because they would seek to increase their milk output, but to increase the future pool of heifers. Retaining more of older cows and thus increasing overall herd size, however, will increase in the short run the share of less productive animals in the herd, and will work to decrease yield, even while increasing milk production. We see therefore, that there can be no clear theoretical prediction as to expected effect of changes in economic environment to immediate changes in yield, for described two effects can cancel each other out, or either can dominate the other. Within one period after the change has occurred, we would expect the short-run adjustments to settle, and for that reason, in addition to current period prices, we include prices of milk and feed in period *t-1* as explanatory variables. We further try to capture the adjustment dynamics in yield equation by including the lagged yield as one of the explanatory variables.

Besides technology and herd structure variables, and economic environment, third category of explanatory variables are dummy variables that capture the impact of changes in government policies. There are three federal programs that we include in our model. Dummy variable *Dum84* captures the effect of Milk Diversion Program enacted in 1984, that that offered payments to farmers for all dairy cows left idle. Although program was running for only one year, since it is expensive to keep idle cows on feed, we assume that culling and replacement decisions in that year were influenced by this policy, with cows being more likely to get culled, and female calves more likely to be grown to replacement heifers to substitute for the culled cows in the subsequent years after the end of policy-based incentives. This policy was part of the comprehensive package of measures that sought to decrease the chronic surplus of milk production that came about as consequence of 5 years of misplaced diary policy whose origins can be traced to late 1970s when milk support price was set too high. One can argue that policy makers have mistakenly interpreted small short-run price responsiveness of milk supply as the proof that support prices were not significantly above free market equilibrium level. What passed unnoticed at that time was the difference in magnitude between small immediate price responsiveness of milk supply and much higher long-run supply responsiveness. In long run, over the course of five years, herd size significantly adjusted to economic incentives, with much of the extra milk produced ending in government stocks targeted for foreign aid, and financed by ever increasing federal budget deficit. Milk Diversion Program was complemented by much more thorough Dairy Herd Termination Program, also known as "Whole-herd Buy-out program", active from September 1986 to the end of 1987, and accounted for by variable *Dum86.* Under the provision of that program, government paid farmers to exit the market, by offering them to sell their entire herd for slaughter at above market prices. Culling decision in 1986 and 1987 were more influenced by that program than the prices that otherwise dictate the herd size levels and structure changes.

This completes the description of the econometric model. Next section describes in further detail the data used in estimation.

4. Description of data

Table 4.1.

Descriptive Statistics for Model Variables

Variable	Units	Description	Mean	St. dev.	Min.	Max.
COW_t	1,000 Head	Dairy cows, USDA Cattle inventory, January 1	10,552	1322	8,990	14,452
HEF_t	1,000 Head	Replacement heifers, 75% of published cattle inventory data for January 1 “500+ lbs heifers”	3,066	203	3,442	4,770
YLD_t	lbs/head/year	Yield per cow	15002	2,999	10,293	20,267
FC_t	$2007/cwt	Feed cost, 16% protein dairy feed	24.58	7.04	13.25	35.21
MP_t	$2007/cwt	All milk price. MILC payment added for 2001-2006	9.23	3.55	4.87	19.33
SP_t	$2007/cwt	Omaha/Sioux Falls boning utility cow slaughter price	81.91	29.27	40.08	153.62
AGE_{ij}	#	Age of i-th productive age class at j-th culling period	--	--	3	11
Dum84	0/1	Dummy variable for Milk Diversion Program, active in 1984	0.03	--	--	--
Dum86	0/1	Dummy variable for Whole-Herd Buy-Out Program, active in 1986-87	0.06	--	--	--
$PROD_t$	Mil lbs	Total U.S. Milk production, calculated as identity: PROD=COW x YIELD	149,516	17,929	116,235	185,078

In this section we provide detailed description of dependent and explanatory variables used in the model. There are four dependent variables in our model. Dairy herd size, denoted COW_t in equation (6), is comprised of all dairy cows. Number of adult bulls used for reproduction purposes is around 10 times less than number of dairy cows, and their impact comes primarily through genetic progress. We thus focus only on female animals in our model. We use USDA January, 1 cattle inventory survey as data for adult cows. Same source is used for per cow yield, denoted YLD_t in equation (9). To calculate number of replacement heifers, denoted HEF_t in equation (8), we multiply USDA January, 1 Cattle inventory data for "500lbs+ heifers" by 0.75. As explained in previous section, calves that are between 8 and 12 months of age on January 1 when survey is done, weigh between 500 and 800 lbs, and are included in USDA reports as replacement heifers. Nevertheless, those animals are too young to give birth in the current period. With pregnancy duration of 9 months, a heifer must be impregnated no later than the end of March to freshen before the end of the period. Since heifers are inseminated at 15 months of age, only those animals that are at least 1 year old should be treated as replacement heifers according to definition we employ for the purposes of this model. If we assume that there are 3 times more heifers of age 12-24 months then heifers of age 8-12 months our correction coefficient *(0.75)* is well justified. One might make case for different specification of this correction procedure, using inventory accounting to arrive at numbers of heifers that have actually entered the herd in period *t*. Schmitz (1997) follows such approach in his research on beef industry, and calculates beef replacement heifers as sum of annual beef herd size change and number of beef cows that have been slaughtered or have died. Employing similar procedure to dairy sector will not help reduce noise in heifers data, as slaughter numbers for dairy cows are much less reliable than estimates of slaughtered beef cows, due to, among other things, biased accounting procedures in those slaughterhouse which service mostly beef industry.

Milk, feed and cow slaughter prices used in the model are all expressed in 2007 dollars. It is worth noticing that correlation among real prices is much higher than correlation among price-ratios or among nominal prices. Explanation for that is found in the sustained long-run trend in decline of real prices for all three variables. This feature should be kept in mind when interpreting the significance levels of estimated coefficients. For milk price we use "All milk" price per cwt (hundredweight) published by USDA. In 2001 federal government instituted Milk Income Loss Contract program with the purpose to curb the impact of decline in milk price on small and medium-size farmers. We account for that program by calculating average annual per cwt payment and adding it to "all milk" price for years 2001-2006. We use USDA formula for 16% protein dairy feed to calculate price of feed that is composed by 41% corn, 8%

soybeans and 51% dry alfalfa hay. For cow slaughter price we use Omaha and Sioux Falls bonning-utility grade cow slaughter price. Trends and volatility risks of these prices were described in more detail in Chapter 2.

Dummy variables Dum84 and Dum86 correspond to Milk Diversion Program and Milk Production Termination Program which were policy interventions in 1984 and 1986 to reduce the dairy herd size in face of sustained surplus production. More details on these policies can be found in Glaser (1986).

5. Statistical inference

5.1. Estimation

Estimation period for the model spans from 1975 to 2007 - the last year for which data can be obtained, which gives us total of 33 observations of dependent variables. In 1970 USDA changed the categorization of dairy cattle from age-based to weight-based system. Since that change artificially reduced the published number of dairy cows by 2 million from 1969 to 1970, we use USDA “January average” series for dairy cows for all years prior to 1970, which corrects for the inventory definition change. Unfortunately, there is no published data that corrects for change in definition of heifers. For that reason, although data for all dependent and explanatory variables are available from as early as 1951, we refrain from setting the first year in estimation period earlier than 1975.

We estimate each of the three stochastic equations separately using the least squares method. Yield equation (9) is estimated by OLS and equations for cows (6) and heifers (8) are estimated by nonlinear least squares, using Gauss-Newton (GN) algorithm in numerical minimization. When sum of squared errors (SSE) function is not globally convex over parameter space and there are multiple local minima, the result obtained by numerical minimization will depend on initial values of coefficient supplied as inputs to start the first iteration of the algorithm. As a consequence, unless initial values are in the convex neighborhood of global minimum, GN will likely converge to local, not global minimum. To insure against such event, we run the GN algorithm multiple times, each time starting with different, randomly drawn vector of starting values for coefficients. We chose the number of rounds minimization is run in such way to be able to have confidence we have uncovered all local minima. Among returned local minima, global minimum is then identified by simple ranking of SSE values.

In very small samples, and especially when model in question is highly non-linear, applicability of large sample theory is very limited, and any estimate of asymptotic standard errors of the coefficients must be taken with caution. One clear indicator that large sample theory performs poorly for some model would be that bootstrap estimates of confidence intervals of coefficients are much different than confidence intervals based on asymptotic theory. To check if our model features such discrepancy, we use residuals-based bootstrapping, simulating the data generating process in the model. Herd dynamics are fully modeled by equations (6) and (8). It will be help us to think of observed data as truly generated by processes modeled by cows, heifers and yield equation with unknown equation parameters and distribution of errors that are assumed to be i.i.d, but not necessarily normal.

What we seek to do in bootstrap procedure is to create simulated samples that are generated by the processes that have the same functional form but coefficients estimated on the original sample imputed as the true parameter values. We simulate unobserved errors using random draws from joint empirical distribution of estimation residuals. Since true processes have occurred sequentially, one year at a time, with observed values (realizations of draws) of cows and heifers influencing the generating process in the next periods, it is both intuitive and logical that bootstrap should follow the same logic of sample generation. This method of drawing is best explained using a step-by-step illustration:

(1) Estimate the all three equations separately. Concatenate vectors of residuals from equations in a matrix that has three columns and whose number of rows corresponds to number of observations.

(2) Use coefficient estimates to predict the number of heifers, cows and yield in 1975, which is the first year in estimation period. Randomly draw a row from matrix of estimation residuals, and from such chosen vector of residuals, add residual from heifer equation to predicted number of heifers, residual from cows equation to predicted number of cows, and residuals from yield equation to predicted yield. Sum of predicted values and random residuals creates simulated values for heifers, cows and yield.

(3) To obtain simulated value for heifers, cows and yield in 1976:

    a. Predict number of cows in 1976, using simulated cows and heifers in 1975 as explanatory variables in cows equation. For all other explanatory variables (prices, technology, policy dummies) use actual data for 1976. In similar fashion predict heifers and yield in 1976.

b. Add randomly chosen residuals to obtain simulated values for three dependent variables.

(4) Repeat step (3), year by year, for the rest of the years in estimation period, always using already obtained simulated values for previous years as regressors wherever lagged dependent variables and their ratios enter as explanatory variables in any equation. Steps (1)-(4) create one sample from the joint distribution of heifers and cows, given assumed data generating process governing herd dynamics.

(5) Re-estimate the cows, heifers and yield equation using simulated sample, and store results of the estimation.

(6) Repeat steps (1)-(5) 4000 times.

We use percentile-t method to obtain bootstrap confidence intervals of parameter estimates and compare them with asymptotic confidence intervals (Hansen, 2008).

5.2. Results

In cow and heifer equation, positive coefficient sign for a variable means that increase in the value of that variable will increase the culling rate. We would thus expect to see the coefficient of milk price to be negative, and coefficients of feed and cow slaughter price to be positive. Technological progress in heifers management would be indicated by negative sign in trend variable in heifers equation. Both federal policies represented by dummies were expected to decrease herd size so sign of corresponding dummy variables are expected to be positive in cow equation. Even though it decreased the number of dairy cows, Milk Diversion Program of 1984 could be expected to increase the number of replacement heifers so the sign of *Dum84 variable* is expected to be negative.

Estimation results are presented in table 5.1.

Table 5.1.
U.S. Dairy Production Model (1975-2007)

$$(5.1)\quad HEF_t = \frac{1}{2}COW_{t-2} \Big/ \left[1+\exp\left(\underset{(0.150)}{0.758} - \underset{(0.003)}{0.019}T - \underset{(0.030)}{0.136}Dum84 + \underset{(0.003)}{0.126}Dum86 - \underset{(0.006)}{0.016}MP_{t-1} + \right.\right.$$

$$\left.\left. + \underset{(0.008)}{0.022}FP_{t-1} + \underset{(0.001)}{0.003}SP_{t-1} - \underset{(0.005)}{0.011}MP_{t-2} + \underset{(0.008)}{0.014}FP_{t-2} - \underset{(0.001)}{0.003}SP_{t-2}\right)\right] \qquad R^2 = 0.883$$

$$(5.2)\quad COW_t = \sum_{i=1}^{9} H_{t-i} \Big/ \left\{\prod_{j=1}^{i}\left[1+\exp\left(-\underset{(0.789)}{2.694} + \underset{(0.079)}{0.151}Dum84 + \underset{(0.031)}{0.231}Dum86 - \underset{(0.057)}{0.063}MP_{t-j}\right.\right.\right.$$

$$+ \underset{(0.087)}{0.249}FP_{t-j} + \underset{(0.007)}{0.002}SP_{t-j} - \underset{(0.167)}{0.213}AGE + \underset{(0.010)}{0.008}MP_{t-j}\cdot AGE$$

$$\left.\left.\left. - \underset{(0.016)}{0.044}FP_{t-j}\cdot AGE - \underset{(0.001)}{0.001}SP_{t-j}\cdot AGE + \underset{(0.316)}{0.980}\frac{HEF_{t-j}}{COW_{t-j}}(AGE-3)\right)\right]\right\} \qquad R^2 = 0.991$$

$$(5.3)\quad YLD_t = \underset{(1381.36)}{5093.17} + \underset{(50.77)}{204.89}T - \underset{(142.29)}{463.26}Dum84 - \underset{(15.16)}{17.75}MP_t + \underset{(34.35)}{28.29}FP_t + \underset{(15.23)}{38.08}MP_{t-1}$$

$$- \underset{(26.48)}{8.04}FP_{t-1} + \underset{(0.15)}{0.40}YLD_{t-1} \qquad R^2 = 0.998$$

$$(5.4)\quad PROD_t = YLD_t \times COW$$

Notes: Asymptotic standard errors are in parenthesis below the parameter estimates. The variables are defined as follows: HEF_t is number of replacement heifers intended to enter the herd in the current year, calculated as 75% of heifers over 500lbs. on dairy farms on 1 Jan. (1,000 head); COW_t is annual average number of dairy cows on dairy farms (1,000 head); MP_t is milk price received by farmers ($/100lbs); FC_t is value of 16% protein dairy ration (51% corn, 41% hay, 8% soybeans) ($/100 lbs); SP_t is Omaha/Sioux Falls slaughter cow bonning/utility price ($/100 lbs); T is time trend (1=1975; 2=1976; etc.); $AGE = (i - j + 3)$ in equation (5.2); $Dum84$ is policy dummy variable for "Milk Diversion Program" active in 1984. $Dum86$ is policy dummy variable for "Whole-herd Buy-out Program" active in 1986-87. YLD_t is production per cow in year t; $PROD_t$ is U.S. milk production (billion lbs).

All three equation exhibit high degree of in-sample prediction accuracy, with maximum absolute prediction error of 2.2% in cow equation, 3.62% in heifer equation and 2.51% in yield equation.[5] Graphs with actual and predicted data, together with bootstrap simulated confidence intervals are presented in figure 5.1.

In heifer equation, all coefficients are significant at 5% confidence level. In cow equation, coefficients for milk price, and interaction of milk price and cow age are not individually significant.

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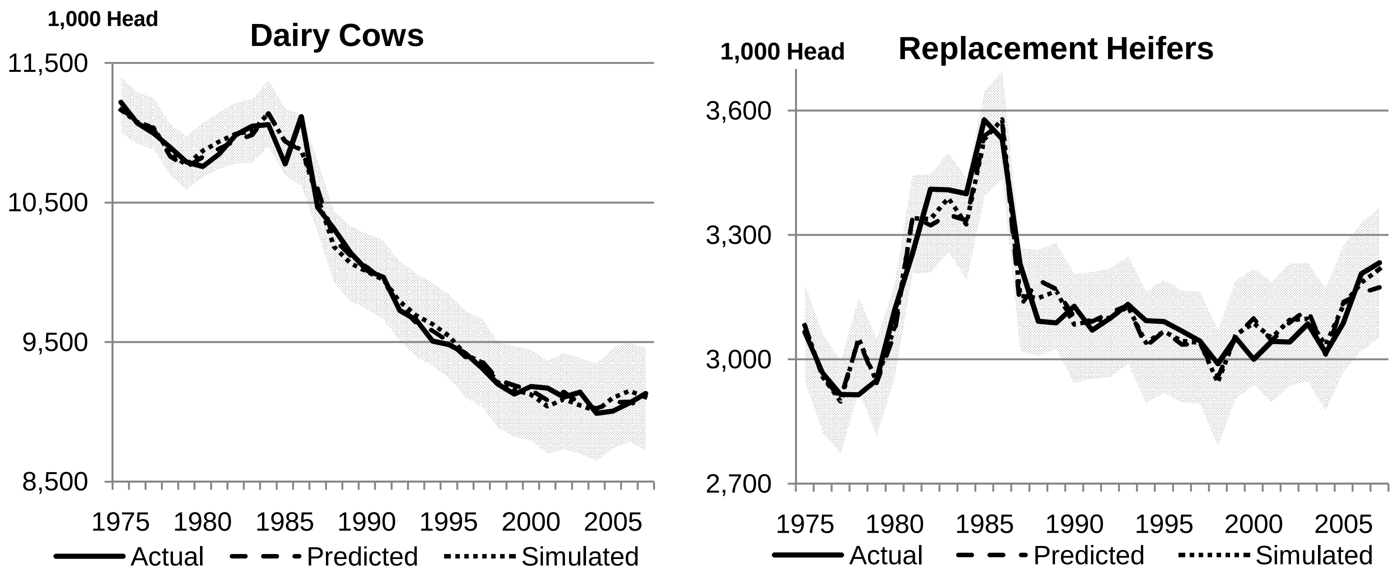
[5] For dependent variable y_i Maximum absolute prediction error is calculated as $\hat{e}_{MAX,\%} = \max_i \left\{\frac{\hat{y}_i - y_i}{y_i} \times 100\right\}$

Figure 5.1.

In-sample prediction for dairy cows and replacement heifers



Lack of significance of milk price coefficient merits sound explanation, for no model that seeks to explain diary supply can be considered as reasonable if the price of principal product (milk) is not shown to be influencing the supply. One plausible explanation for these results is that it is difficult to differentiate between average and age-specific impact of change in milk price to culling rates. To see if employed model specification is still reasonable, we test for joint significance of coefficients for average and age-specific impacts of milk price. Results of Wald tests for all three prices are reported in table 2.

Table 5.2.

Tests for joint significance of price and price-age interaction variables

	Price	p-value	Price-age	p-value	Wald	p-value
Milk	-0.0699	0.25	0.0095	0.41	18.65	0.00
Slaughter	0.0023	0.75	-0.0006	0.68	2.05	0.36
Feed	0.2438	0.01	-0.0430	0.01	8.99	0.01

Critical value of test statistic: $\chi^2_{2df,95\%} = 5.99$

We see that combined average and age-specific impacts of prices of milk and feed are highly significant. We do not see any significance for cow slaughter price. That should not be very surprising. Over the last 25 years, yield per cow has doubled. That means that salvage value of cow comprises much small fraction of present discounted value of future earnings from the cow. Consequently, culling decisions are to much higher degree influenced by prices of milk and feed than by cow cull price.

Since all parameters in heifers and cows equation are in the exponent of the logistic function, it is not straightforward to see the magnitude of price changes impact on culling rates in the short run. To address this issue, in table 3 we present predicted marginal impact of price changes on culling rates of each cow productive age class in 2007. Cull rates are given in the second column, and the rest of the table shows changes in the culling rates induced by 10% change in prices. For example, culling rate for cows in second productive age class, which corresponds to 4 years of age, is 17.3%. That means that out of all the cows that survived first year in the herd, 17.3% will be culled in 2007. Increase in milk price by 10% over average milk price for 2007 (19.13 USD/cwt) would decrease the culling rate by 0.9%.

Table 5.3.

Predicted marginal impact of prices on culling rates in 2007.

Age	Cull rate	Marginal impact of prices, 10% increase over 2007 level					
$i+2$	k_{ti}	$\Delta MP \rightarrow \Delta k_{ti}$		$\Delta FP \rightarrow \Delta k_{ti}$		$\Delta SP \rightarrow \Delta k_{ti}$	
3	12.6%	-0.8%	(0.5%)	0.9%	(0.3%)	0.0%	(0.2%)
4	17.3%	-0.9%	(0.4%)	0.7%	(0.2%)	0.0%	(0.1%)
5	23.4%	-0.8%	(0.2%)	0.4%	(0.2%)	0,0%	(0.1%)
6	30.7%	-0.5%	(0.4%)	-0.2%	(0.2%)	-0.1%	(0.1%)
7	39.2%	-0.2%	(0.9%)	-0.9%	(0.4%)	-0.2%	(0.3%)
8	48.4%	0.3%	(1.5%)	-1.7%	(0.7%)	-0.3%	(0.5%)
9	57.7%	0.7%	(2.0%)	-2.4%	(0.9%)	-0.3%	(0.6%)
10	66.5%	1.0%	(2.3%)	-2.9%	(1.2%)	-0.4%	(0.7%)
11	74.2%	1.2%	(2.4%)	-3.1%	(1.3%)	-0.4%	(0.8%)

Both Wald test and tests for significance of marginal impacts of prices on culling rates indicate that our model shows statistically significant impact of milk price on cow herd dynamics. However, in herd-dynamics models it makes much more sense to focus ones attention not to short-run, but medium- and long-run changes in herd size and milk production that are induced by price changes. We address these type of questions in the next section.

6. Post-estimation and Simulations

In addressing long-run impacts of prices on herd-dynamics, we consider ten years to be sufficiently long period for major adjustments to changes in economic environment to take place.

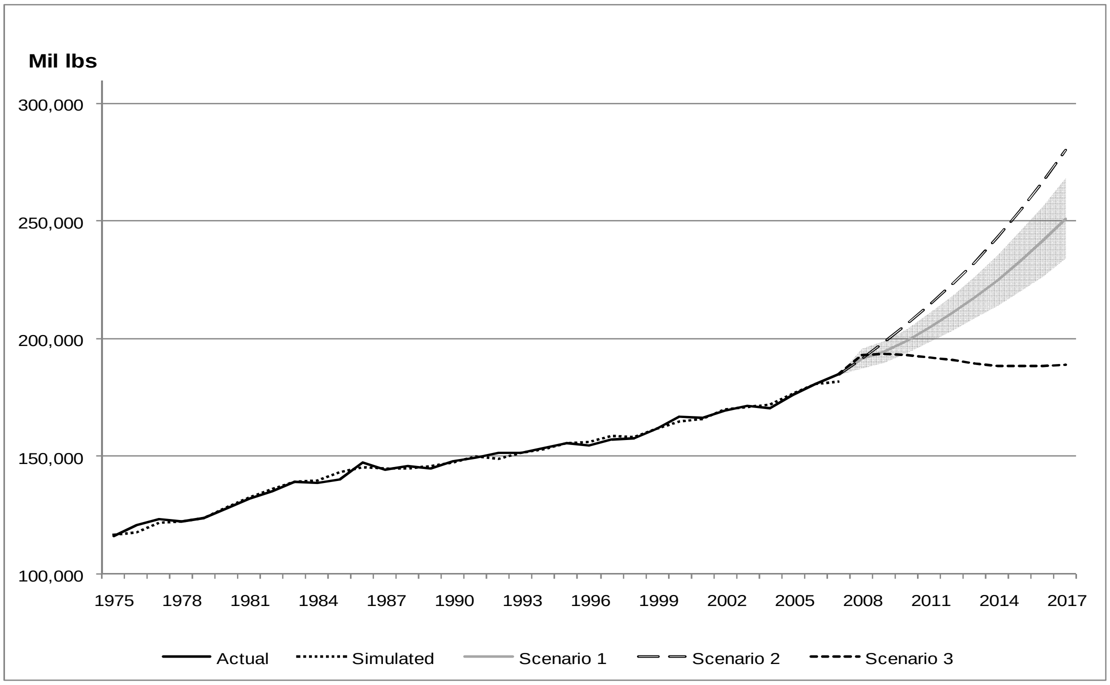
Under that assumption, we ask the following question: if real prices remain constant over the next ten years, what will be the total amount of milk produced ten years from now. Taking different prices as starting values in this simulation gives us three insightful scenarios. Since we want to investigate the developments under favorable, unfavorable and average economic environment, we build scenarios in the following way:

- Scenario 1: Prices stay at mean of 2005-2006 level. This constitutes an "average" economic environment
- Scenario 2: Prices stay at 2007 level. 2007 was a good year for dairy industry in USA, as milk price soared to 19.14USD/cwt, up from 13.53USD/cwt in 2006, with year-to-year feed costs rising much less than price of milk. Therefore, this scenario constitutes "favorable" economic environment.
- Scenario 3: Following high gas prices, higher food exports and increased demand for crops from bio-fuels sector, mixed dairy feed prices have doubled in the first half of 2008 over their 2007 level. To investigate the long-run impact of "unfavorable/high feed-cost" scenario, we assume that prices over the next ten years stay as following: corn - 5.5USD/bu, soybeans – 12USD/bu, hay alfalfa (dry) – 165USD/ton.

All scenarios assume unabated continuing improvements in yield per cow, as parameterized by yield equation (5.3). Figure 6.1. shows milk production under all three scenarios. To keep the graph clear, we have plotted bootstrapped confidence interval for scenario 1 only.

Figure 6.1.

Scenario Forecasts of US Milk production, 2008-2017



Similar exercise can be undertaken by focusing on price-responsiveness directly, instead of building scenarios. In other words, we can ask what the long-run elasticity of herd size and milk production to price changes is. How long-run elasticities are calculated is best explained by an example:

1) Choose the year which you want to use as starting period. For example, let starting year be 2005.
2) Set real prices for the next 30 years to be the same as in the starting year. We call this “base scenario”. 30-year period that begins with starting year is called simulation period.
3) Simulate the number of cows, heifers and the total milk production would be in each year of the simulation period. Use random draw from estimation residuals as forecast errors in each step of dynamic simulation.
4) Choose the variable with respect to which elasticities are to be calculated. In example, let the variable of choice be milk price.
5) Set milk price in starting year to be 10% higher than the observed and used in “base scenario”. Leave the prices of feed and cull unchanged.

6) Again set the prices for the next 30 years to be the same as in starting year. This corresponds to situation where economy experiences one-time permanent price shock, as price of milk has increased by 10% in starting year and remained fixed at the increased level. We call this “alternative scenario”.
7) Simulate the number of cows, heifers and the total milk production under “alternative scenario” in each year of simulation period, using the same vector of forecast errors as in “base scenario” simulation.
8) For each year in the simulation period, calculate the difference in number of cows, heifers and milk production under “alternative” and “base scenario”. Standard definition of elasticity is percent change in variable of interest per percent change of the influencing variable. Therefore, in our case, to complete the calculation of elasticity, divide the calculated difference between two scenarios by the value under “base scenario”, and divide again by 0.1 to account for 10% change in price.

To summarize, while standard elasticity measures what “would be if price increases now” vs. “what is now”, for long-run elasticities we need to compare “what would be if price stay the same” vs. “what would be if price increases now, and stay at the new level”.

To calculate confidence intervals of elasticities, repeat the steps 1-8 over one thousand rounds, each time taking as equation parameters a random draw of bootstrapped coefficients in heifer, cow, and yield equation. Endpoints of confidence intervals correspond to 2.5 and 97.5 percentiles of distribution of bootstrapped long-run elasticities.

Numbers presented in table 6.2. are average of elasticities calculated taking as starting year each year in the period 2003-2007, and bounds of confidence intervals are calculated as simple average of bounds of confidence intervals for each starting year in the stated period. To see how price responsiveness has changed over years, same calculations are done for the period 1978-1982.

Table 6.1. **Short-Run and Long-Run Elasticities of U.S. Dairy Supply**

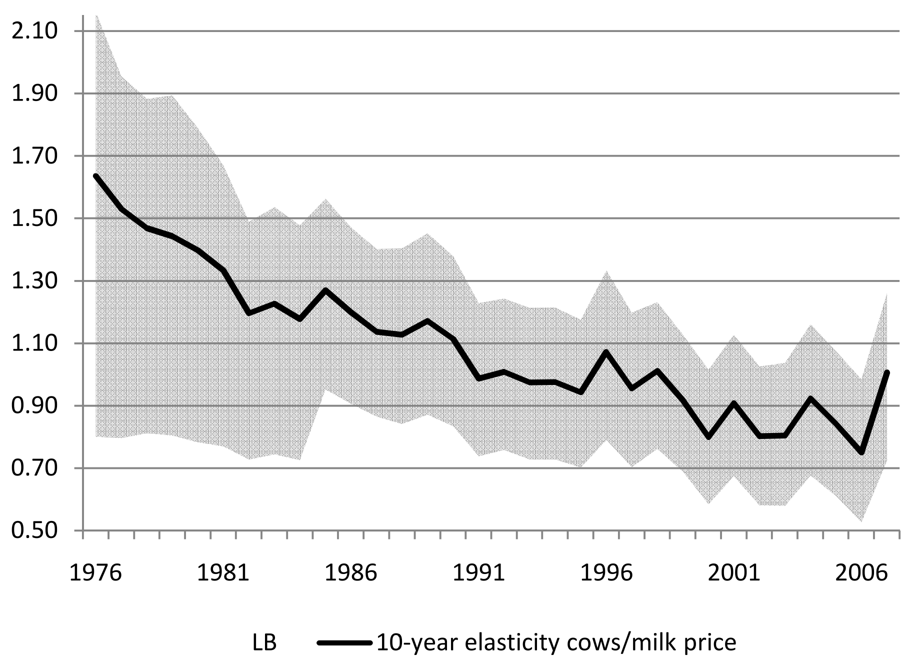
1978-1982	Years since Price Change (*j* Years)														
	1			3			6			10			25		
	Point	Low	High	Point	Low	High	Point	Low	High	Point	Low	High	Point	Low	High
Elasticity of															
HEF_t w.r.t. MP_{t-j}	0.277	0.105	0.449	0.551	0.337	0.718	0.949	0.628	1.205	1.573	1.062	1.979	3.950	2.609	5.050
COW_t w.r.t. MP_{t-j}	0.051	-0.102	0.091	0.293	0.104	0.378	0.737	0.453	0.909	1.361	0.867	1.697	3.749	2.406	4.797
$PROD_t$ w.r.t. MP_{t-j}	0.086	-0.070	0.190	0.374	0.165	0.496	0.823	0.527	1.016	1.443	0.940	1.792	3.823	2.481	4.877
Elasticity of															
HEF_t w.r.t. FP_{t-j}	-0.139	-0.227	-0.051	-0.251	-0.326	-0.122	-0.422	-0.559	-0.180	-0.729	-0.977	-0.295	-1.630	-2.182	-0.606
COW_t w.r.t. FP_{t-j}	-0.004	-0.047	0.123	-0.113	-0.209	0.086	-0.350	-0.524	-0.021	-0.649	-0.934	-0.122	-1.582	-2.174	-0.466
$PROD_t$ w.r.t. FP_{t-j}	0.026	-0.037	0.164	-0.083	-0.189	0.125	-0.323	-0.504	0.010	-0.626	-0.914	-0.093	-1.566	-2.159	-0.445

2003-2007	1			3			6			10			25		
	Point	Low	High	Point	Low	High	Point	Low	High	Point	Low	High	Point	Low	High
Elasticity of															
HEF_t w.r.t. MP_{t-j}	0.123	0.047	0.198	0.282	0.197	0.357	0.526	0.394	0.648	0.869	0.651	1.071	2.207	1.593	2.819
COW_t w.r.t. MP_{t-j}	0.066	0.027	0.091	0.226	0.155	0.286	0.488	0.357	0.610	0.835	0.611	1.046	2.204	1.568	2.848
$PROD_t$ w.r.t. MP_{t-j}	0.076	0.031	0.116	0.251	0.171	0.315	0.514	0.375	0.638	0.861	0.631	1.075	2.228	1.586	2.876
Elasticity of															
HEF_t w.r.t. FP_{t-j}	-0.061	-0.100	-0.022	-0.122	-0.156	-0.077	-0.232	-0.293	-0.138	-0.390	-0.494	-0.217	-0.960	-1.234	-0.480
COW_t w.r.t. FP_{t-j}	-0.012	-0.028	0.023	-0.088	-0.131	-0.014	-0.219	-0.298	-0.083	-0.379	-0.503	-0.161	-0.968	-1.267	-0.438
$PROD_t$ w.r.t. FP_{t-j}	-0.003	-0.025	0.037	-0.079	-0.126	-0.001	-0.210	-0.290	-0.070	-0.371	-0.496	-0.151	-0.962	-1.262	-0.429

Several observations emerge from the table above. First, whatever the starting year, long-run elasticities are much higher than short- and intermediate-run elasticities, in alignment with our statement that herd adjustments to price changes take time to unravel. Second, by comparing average long-run elasticities across different starting periods, we see that price-responsiveness of dairy industry has not increased over the last 25 years. One might expect that with better genetics, improved heifers management and larger farms, industry would be likely to react to prices more quickly, using improved technology to faster adjust to changes in economic environment. Table above indicates that might not be the case. To investigate this issue further, we plot the 10-year elasticities, calculated for each year in the sample.

Figure 6.2.

Long-run elasticities of herd size to milk price



While the mean of the elasticity is showing clear downward trend, bootstrapped confidence intervals are large enough that i.e. point estimate for 10-year elasticity in 2007 falls within confidence interval for elasticity calculated in 1980, and vice versa.

When thinking how to formally test whether price-responsiveness has changed, first notice that distributions of long-run elasticities at different starting years are not likely to be independent. For example, if one round of bootstrapped coefficients produces above-average long-run elasticity taking 1980 as the starting year, it is likely to produce above-average long-run elasticity when starting year is 2007.

In formal testing we take as null hypothesis the statement that 10-year elasticities are the same in 1980 and 2007. Alternative hypothesis is that 10-year elasticity in 1980 was higher than in 2007. We simulate the distribution of differences between 10-year elasticities in the years 1980 and 2007. If null hypothesis is correct, than distribution of differences should be roughly centered around zero, i.e. about half of bootstrap rounds should show elasticity in 1980 to be higher, and in other half of the rounds elasticity in 2007 should be higher. We reject null hypothesis if number of rounds in which 2007 is more price-responsive than 1980 is less than 5% of total number of bootstrap rounds. Results of testing are presented in the table below.

Table 6.2.

Tests for significance of change in long-run elasticity

$\Pr\left(\eta_{2007} > \eta_{1980}\right)$	Milk	Feed
Hef	0.0065	0.0288
Cow	0.0490	0.1195
Yld	0.0848	0.8775
Prod	0.0355	0.1413

One-sided hypothesis test: Reject $H_0 : \eta_{1980} = \eta_{2007}$ if $\Pr\left(\eta_{2007} > \eta_{1980}\right) < 0.05$

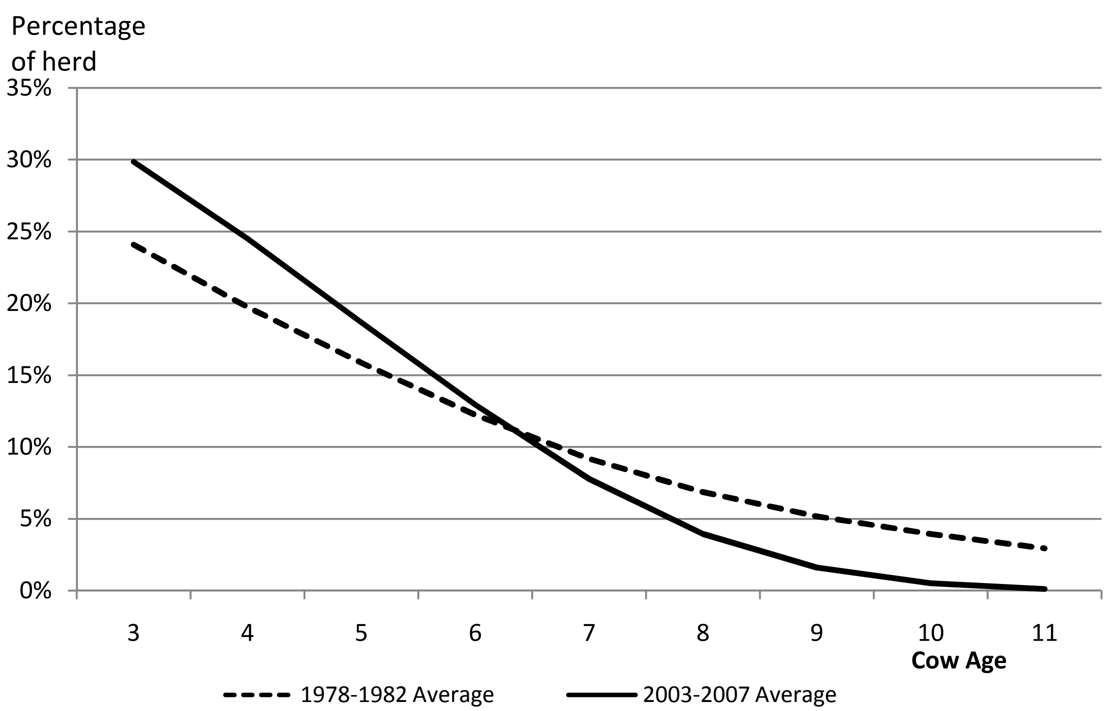
According to this test, we can conclude that 10-year elasticities of heifers, cows and total milk production with respect to milk price were higher in 1980 than in 2007. As for the feed price, we can only conclude that elasticity of number of heifers to feed price was higher in 1980, while results are inconclusive for number of cows and total milk production. Since elasticities with respect to cull price are insignificant in the first place, we do not perform this test for that price.

What can we infer from different results for milk and feed price? Although our model does not explicity treat price increases and decreases asymmetrically, one tentative conclusion can still be that industry is just as responsive in 2007 as it was in 1980 with respect to adverse changes in economic environment (i.e. increase in feed price), while responsiveness to favorable changes (i.e. increase in milk price) has decreased. The conclusion that long-run elasticities have declined is unexpected, and we here attempt to provide reasonable explanation for it.

While we only observe annual inventory data for cows, the structure of our model allows us to predict the herd structure by age at any year in the sample. In figure 6.5. we have plotted distribution of herd by age of the cows. We see that herd was much more balanced in the period 1978-1982, with higher share of older cows, and smaller share of young cows than in the period 2003-2007.

Figure 6.3.

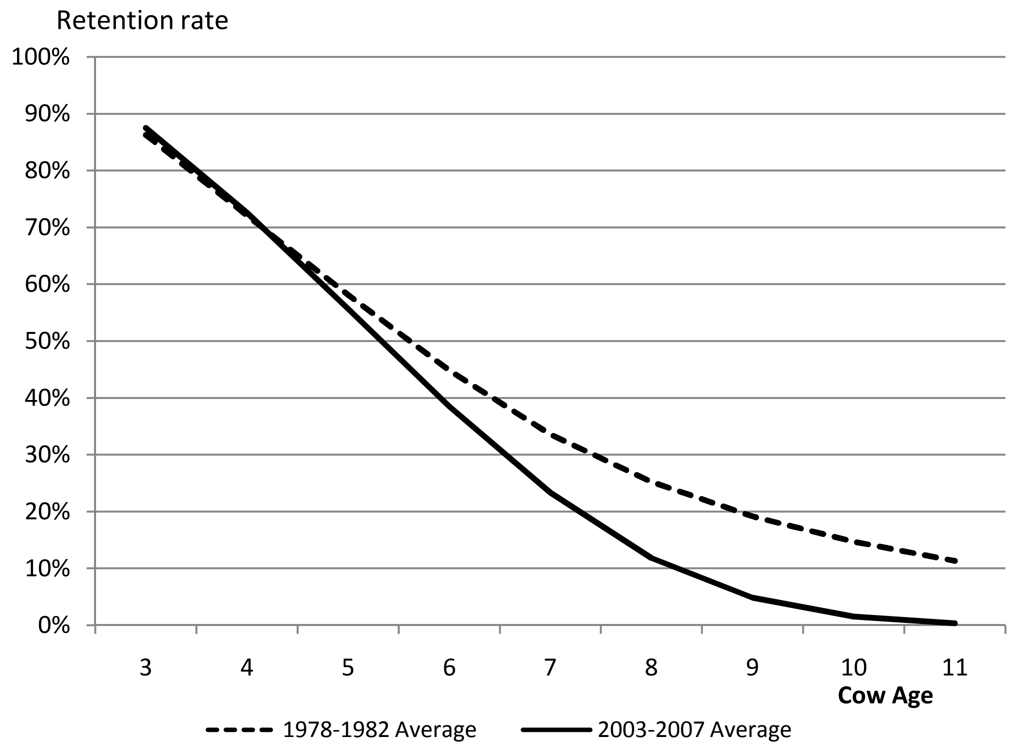
Predicted Structure of US Dairy Herd by Cow Age Class



To understand what caused that change in age structure of the herd, we plot retention rates for both periods for each cow age class in Figure 6.6. below. Now it becomes clear that it was faster removal of older cows that tilted the age distribution.

Figure 6.6.

Predicted Retention Rates



What this figure tells us is that advancements in herd management that have focused on increasing yield per cow have as a consequence much younger herd. While retention rates of cows of age 3-5 (first three lactations) have remained the same in 2003-2007 as in 1978-1982 period, older cows are significantly less likely to be kept in herd.

Recall that key adjustments in farm management to changes in economic environment is done by culling and replacement decisions, i.e. we consider culls to be an economic decision, not something determined by biological constraints. When farmers observe positive changes in economic environment, if they want to expand their herd, they can do one of two things. First, keep cows longer in the herd adding as much new heifers as they did before, and second, increase the share of female calves that are grown into replacement heifers and ultimately added to the herd. Define replacement ratio as ratio of replacement heifers to adult dairy cows. The younger the herd is, the higher replacement ratio needs to be to keep the herd size unchanged.

We argue that reduction in long-run price responsiveness is the result of increase in involuntary cull rates that makes it hard for farmers to increase the retention rate of cows in the process of adjustment to favorable changes in economic environment. Hadley (2006) reports that in DHI herds health culls, i.e. culls induced by health problems of a cow, constitute 79.5% of all culls. If the share of health culls in all culls has increased over time that would imply that culls are less starting to be less of an economic decision, and are increasingly a consequence of biological constraints. Furthermore, health culls are greater constraint on expansion, then on reducing the herd, for farmer can always decide to increase the cull rate up to 100%, but health culls represent the lower bound beyond which culls cannot be easily or cheaply reduced.

We conclude that tremendous increases in productivity did not translate to increases in price elasticity of milk supply. Downside of yield-oriented genetic improvements and ever increasing stables is large share of involuntary culls. Improvements in productivity has shifted supply curve to the right, but have also made it more steep. In a situation where major share of replacement heifers go just to maintaining herd size, road to higher responsiveness to favorable economic environment must come not from further improvements in yield, but from wider adoption of sexed semen, which would increase the share of female animals among newborn calves.

7. Local Development Implications of Dairy Policy

Implications of this research for local development are twofold. First, consequences of US liberal policy that does not explicitly put specific spatial and size distribution of milk farms are explored. I have shown in chapter 2. that such policy options lead to massive consolidation and important regional employment shifts. Those outcomes have to be kept in mind as Europe moves closer toward more liberal policy that abandons quotas as primary policy tool.

Second, I have demonstrated though elaborate econometric analysis that productivity gains obtained through unleashed market forces need not lead to increase in price responsiveness of milk supply. Yield-oriented genetic improvement neglects the robustness of cow's health under more demanding production conditions. That in turn produces herds that are younger, but not out of choice, but necessity, as cows of only several lactations become very susceptible to health risks, and need to be removed from the herd. Higher productivity works to reduce the long-run equilibrium market-clearning price of milk. On the other hand, lower price responsiveness means that supply reaction to demand shifts that push the price above the market-clearing level takes more time to push the price back to the long-run equilibrium. Policy maker needs to weigh these two effects and design production rules (i.e. land zoning plans, financial support schemes) to bring about the outcomes they prefer.

To understand local development impacts in Croatia that may come about as EU moves towards more market-friendly agricultural policy, I list here some basic descriptive statistics of dairy industry in Croatia. In Croatia, there were 32,000 milk farms as of 2008, with 177,000 dairy cows, and yearly production of 650 mil liters of milk (Grgić, 2008). That translates to average farm size of 5.53 cows, and yield of 3672 liters/cow per year, or roughly 8200 lbs/cow to use US measures. To gain some idea how that compares to USA, first notice that the entire USA has little more than twice the number of farms than Croatia, although it has 70 times higher population. In terms of productivity, average Croatian farm lags 40 years behind US farm, where 3600 liters/cow was achieved in mid 1960s. However, Croatian dairy sector is undergoing major restructuring, and number of farms has been almost halved from 59,000 to 32,000 in last 5 years.

Table 7.1. **Distribution of Croatian dairy farms by size**

cows on farm	2003		2007	
<3	44562	75.76%	17963	56.2%
4-8	11875	20.19%	9163	28.67%
9-14	1521	2.58%	2.354	7.36%
15-27	666	1.13%	1684	5.27%
>27	191	0.32%	795	2.48%
Total	58815	100%	31959	100%

Source: Based on Grgic, Z (2008a),

All this tells us that Croatian sector is decades behind the US sector analyzed in this work. That should make us careful in drawing direct analogies, but also should also make this paper serve as a valuable “look into the future” should Croatia and EU decide to follow USA and liberalize agricultural policy.

As a conclusion, opting for US system of dairy industry would bring about both increases in welfare to general public but also significant costs to some sectors and regions in Europe where small and inefficient farms dominate. Goals such as spatial cohesion and food security must be taken into account in addition to productivity gains and technological improvements in dairy production that reduce the price of food.

Bibliography

--- (2005): *Dairy Yearbook*. Economic Research Service, Washington D.C.: USDA.
[http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1207]

AMS USDA (2008): National Econometric Model Documentation for Model Calibrated to USDA Agricultural Baseline Projection to 2016, Agricultural Marketing Service Dairy Programs, USDA.

Blayney, D. (2002): The Changing Landscape of U.S. Milk Production, *Statistical Bulletin, 978,* Washington D.C.: USDA.
[http://www.ers.usda.gov/publications/sb978/sb978.pdf]

Blayney, D. et al. (2006): U.S. Dairy at a Global Crossroads*. Economic Research Report, No. 28*. Economic Research Service, Washington D.C.: USDA.
[http://www.ers.usda.gov/publications/err28/err28.pdf]

Chavas, J.P. and R. Klemme (1986): *Aggregate Milk Supply Response and Investment Behavior on U.S. Dairy Farms*, American Journal of Agricultural Economics, Vol. 68, No. 1. (Feb., 1986), pg. 55-66.

Chavas, J.P. et al. (1990): *A Regional Analysis of Milk Supply Response in The United States,* North Central Journal of Agricultural Economics, Vol. 12, No. 2., pg. 149-164.

Grgić, Z. (2008) *Tko će i kako povući naše mjekarstvo naprijed?*, Mljekarski list, 10/2008, ISSN 0351-9104, Vol. 44, pg. 14-16

Grgić, Z. (2008a) *Stanje proizvodnje mlijeka u nas i očekivane promjene – realno ili ne?* Mljekarski list, ISSN 0351-9104, 06/2008, Vol. 44, pg. 15-17

Hansen, B. (2008): *Econometrics*, Manuscript.
[http://www.ssc.wisc.edu/~bhansen/econometrics/]

Huy, B. et al. (1988): *Recent Changes in Regional Structure of U.S. Dairy Production*, Northeastern Journal of Agricultural and Resource Economics, April 1988.

Manchester, A. and D.P. Blayney (2001): Milk Pricing in the United States, *Agriculture Information Bulletin No. 761,* Economic Research Service, Washington D.C.: USDA.
[http://www.ers.usda.gov/publications/aib761/aib761.pdf]
Jesse, E. and B. Cropp (2004): *Basic Milk Pricing Concepts for Dairy Farmers.* Madison, WI: University of Wisconsin-Extension.
[http://future.aae.wisc.edu/publications/basic_milk_pricing.pdf]

MacDonald, J. et al. (2007): Profits, Costs, and the Changing Structure of Dairy Farming, *Economic Research Report No. 47*, Economic Research Service, Washington D.C.: USDA.
[http://www.ers.usda.gov/publications/err47/err47.pdf]

Schmitz, J. (1997): *Dynamics of Beef Cow Herd Size,* American Journal of Agricultural Economics, Vol. 79, No. 2. (May, 1997), pp. 532-542.

Yavuz, F et al. (1996): Spatial Equilibrium Analysis of Regional Structural Change in U.S. Dairy Industry, Review of Agricultural Economics, Vol. 18, No. 4. (Oct., 1996), pg. 693-703.