Marin Božić and Brian W. Gould

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Marin Božić
Research Assistant
The Institute of Economics, Zagreb
Trg J. F. Kennedyja 7
10000 Zagreb, Croatia

Research Assistant
Department of Agricultural and Applied Economics
University of Wisconsin-Madison
311 Taylor Hall, 427 Lorch Street, Madison, WI 53706, U.S.
T. 1 608 239-6079
E. bozic@wisc.edu

and

Brian W. Gould
Associate Professor
Department of Agricultural and Applied Economics
University of Wisconsin-Madison
421 Taylor Hall, 427 Lorch Street, Madison, WI 53706, U.S.
T. 1 608 263-3212
E. bwgould@wisc.edu

www.eizg.hr

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T. 385 1 2362 200
F. 385 1 2335 165
E. eizagreb@eizg.hr
www.eizg.hr

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Contents

Has Price Responsiveness of U.S. Milk Supply Decreased?

Abstract:
This study has three main objectives: (i) to quantify the impacts of milk and feed price changes on the primary milk supply in the U.S.; (ii) to examine the impacts of technological changes on the price responsiveness of supply and specific herd characteristics; and (iii) to generate dynamic long-run forecasts of the milk supply response to price changes and possible future technological advancements. The econometric analysis contained in this study is an update of the model by Chavas and Klemme (1986). We used the residual-based bootstrap to test hypotheses regarding the long-run price-responsiveness of supply, and found that the 10-year elasticity of milk supply to milk price is lower in 2007 than it was in 1980. This result is most surprising. One might expect that with better genetics, improved heifer management and larger farms the industry would be likely to react to prices more quickly than almost thirty years ago, when small and medium-sized dairy operations played a major role. A detailed analysis of the predicted herd structure supports the conjecture that a decrease in price responsiveness is a consequence of decades-long excessive focus on yield improvement in genetic selection. The intensive production process could make cows susceptible to health problems, imposing biological constraints on the economic lifetime of a cow. Hence, herd expansion decisions will be harder to implement, as culling rates are not easily reduced, and more replacement heifers are needed just to keep the herd size stable.

Keywords: milk supply, long-run elasticities
JEL classification: Q11

Smanjuje li se cjenovna elastičnost ponude mlijeka u SAD-u?

Sažetak:
Ovaj rad ima tri glavna cilja: (i) kvantificirati utjecaj promjena cijena mlijeka i stočne hrane na proizvodnju mlijeka u SAD-u; (ii) istražiti posljedice tehnoloških promjena u proizvodnji mlijeka na elastičnost ponude i karakteristike mliječnog stada i (iii) generirati dugoročne dinamičke procjene elastičnosti ponude mlijeka na promjene cijena i buduće tehnološke promjene. Ekonometrijska se analiza temelji na doradi modela kojeg su osmislili Chavas i Klemme (1986). Koristili smo metodu *residual-based bootstrap* kako bi testirali hipoteze o dugoročnoj elastičnosti ponude. Utvrdili smo da je desetogodišnja elastičnost u 2007. bila manja nego u 1980. godini, što nas je iznenadilo. Moglo bi se pretpostaviti da će zbog bolje genetike, unaprijeđenog sustava upravljanja reprodukcijom i većih mliječnih farmi, mliječna industrija na cijene reagirati brže nego prije 30 godina kada su male i farme srednje veličine dominirale sektorom. Detaljna analiza ocijenjene strukture stada potkrepljuje pretpostavku da je pad cjenovne elastičnosti posljedica dugogodišnjeg prenaglašenog fokusa na prinos mlijeka prilikom genetičke selekcije. Intezivni proces proizvodnje mlijeka čini krave podložnima zdravstvenim problemima i nameće biološka ograničenja na dužinu ekonomski isplativog života krave. U takvim će se okolnostima teže provesti odluka o povećanju stada, dok će samo za održavanje veličine stada na stabilnoj razini biti potrebno više junica.

Ključne riječi: ponuda mlijeka, dugoročne elastičnosti
JEL klasifikacija: Q11

1 Introduction*

This paper examines the evolution of U.S. milk production in the 1975-2007 period and the dairy policy environment in which the industry operates. This study has three main objectives: (i) to quantify the current supply structure of the U.S. dairy industry; (ii) to gain insight into impacts of technological changes that have occurred over the last 25 years; and (iii) based on (i) and (ii), to generate forecasts of the long-run milk supply response to price changes and possible future technological advancements.

The structure of the paper is as follows. We first give an overview of the main trends in the U.S. dairy sector, followed by a summary of the U.S. dairy policy. Next, after a brief literature overview, we state the study objectives and describe the econometric model used in this analysis. We follow by a description of the data used in the estimation, an outline of the estimation procedure and a design of post-estimation tests. After presenting estimation results, long-run simulations of milk production and supply elasticities are given. While our research has focused exclusively on the U.S. dairy sector, to make our findings more interesting for the Croatian audience, we wrap up by a brief comparison of U.S. and Croatian dairy sectors, followed by the conclusions.[1]

2 Overview of U.S. Dairy Sector

In 2007, there were approximately 80,000 dairy farms in the U.S., with an aggregate herd size of 9.2 million cows producing 185.6 billion lbs (81.7 billion liters)[2] of milk annually. With this milk, valued at more than US$35.5 billion, the dairy sector accounts for 12 percent of the gross value of the US agricultural production (USDA, 2009). The U.S. dairy industry represented by both dairy farms and processing industries are continuing to experience dramatic structural changes that have been accelerating since the early 1970s.

At the farm level, there is a continued (i) increase in farm size, (ii) evolution in the technologies being adopted (i.e. rBST, sexed semen, rotational grazing feeding systems), and (iii) shifting of the production location away from traditional production areas. Over the last 20 years, the manufacturing sector has seen a dramatic increase in R&D efforts devoted to the marketing of new value-added consumer oriented dairy products, the development of new uses of by-products generated by the production of traditional dairy products (e.g. whey-based products, lactose, dairy-based proteins), the development of the use of ultra-filtration technologies to improve plant productivity, the expansion of the production aimed at replacing the products that have typically been imported (e.g.

* We would like to thank Jean-Paul Chavas and Ed Jesse for helpful comments.

[1] For a more detailed discussion of the material presented here, see Božić (2009).

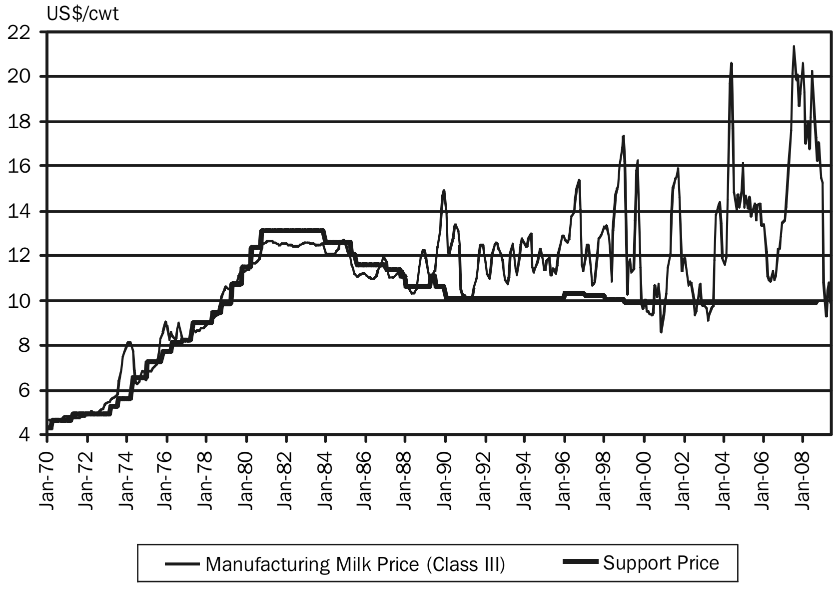
[2] We assume that a gallon of milk weighs 8.6 pounds. 1 gallon = 3.785 liters.

European style cheeses, casein, milk protein concentrate) and an increase in the average processing plant size.

In terms of dairy policy, we have witnessed an evolution of dairy policies that are arguably more market oriented than in the past. Finally, the reliance of the U.S. dairy industry on international dairy markets is becoming much more important. This is evidenced by the current depressed domestic milk prices, which are in part due to reduced dairy exports.

A significant characteristic impacting the U.S. dairy sector is the dramatic increase in the milk price variability. Figure 1 shows the relationship between the manufacturing grade milk price support level and the monthly Class III (BFP/MW) milk price.[3] Prior to the late 1980s, there was very little variability in the manufacturing grade milk price as the price was essentially set by the U.S. manufacturing milk support price. Since the late 1980s, not only has the Class III price diverged from the manufacturing support price but its variability has dramatically increased.

Figure 1 **Relationship Between Class III/M-W and Manufacturing Support Price**



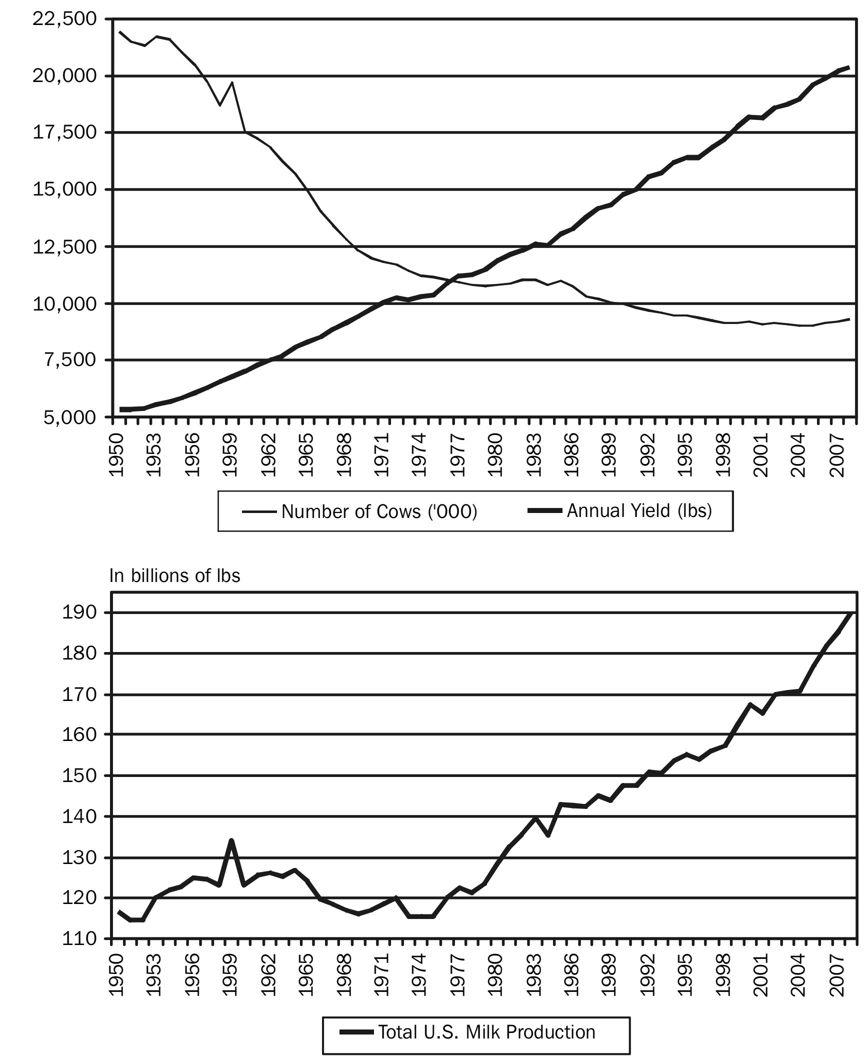
Source: http://future.aae.wisc.edu/.

In terms of its domestic market, total annual dairy product demand is growing in a 2-3 percent range, reflecting a relatively mature market relative to China, Southeast Asia and Latin America, where demand is growing at a rate higher than 10 percent annualy (Blayney et al., 2006). This increased demand has been met with a continuously declining

[3] The Class III (BFP/MW) price is the minimum price paid for milk using in cheese manufacture under the Federal Milk Marketing Order System.

number of more productive milk cows. In Figure 2, we show the number of cows in the U.S. dairy herd and the average annual production per cow.

Figure 2 **U.S. Dairy Herd, Per Cow Productivity and Total U.S. Milk Production 1950-2008**

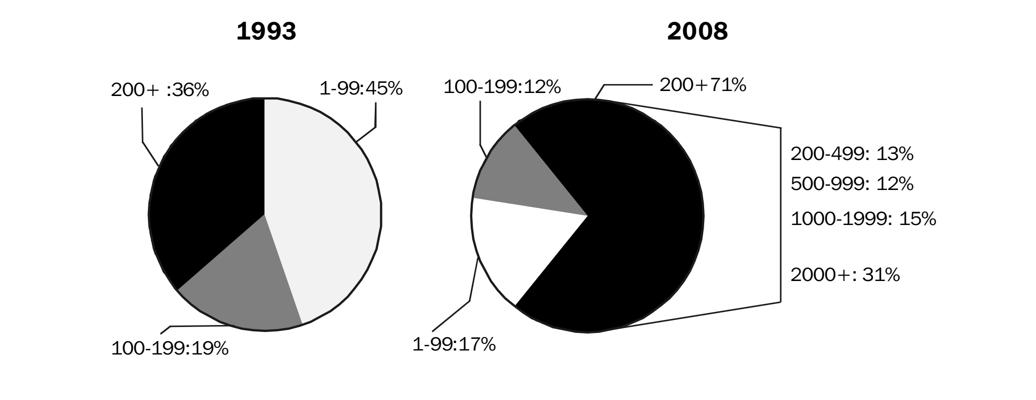


Source: National Agricultural Statistical Service, http://www.nass.usda.gov/.

In 1950, the U.S. dairy herd was composed of 21.9 million cows with an average annual yield of 5,313 pounds (2338.6 liters). By 1975, the dairy herd had decreased by 48.9 percent to 11.2 million heads with an average annual productivity of 10,358 lbs (4559.2 liters), a 94.9 percent yield increase. The 2008 herd size is 42.0 percent of the 1950 herd while producing 63 percent more milk. Over 1950-2008, the average yield increased at a compound annual growth rate (CAGR) of 2.3 percent. In contrast, the size of the U.S. dairy herd was shrinking at the CAGR of -1.4 percent. Combining these two trends shows that the total U.S. production increased at a CAGR of 0.83 percent. Over the 25 year period, 1950-1975, the total U.S. milk production was fairly stable. In contrast, over the last two and a half decades there has been a relatively steady annual growth rate, with the CAGR of 1.4 percent.

The number of dairy farms has decreased from over 300,000 in 1980 to less than 80,000 in 2007 while farm size has quadrupled. Figure 3 shows the distribution of U.S. milk production by herd size for years 1993 (first year for which data are available) and 2008. Over this 16-year period, the average herd size has more than doubled. The contribution to the total U.S. milk production of the <100 cow size grouping has decreased from 45 percent to 17 percent. The 200+ herd size group now accounts for more than 70 percent of production with the 500+ size alone accounting for 54 percent of U.S. output.

Figure 3 **Rise of the Very Large Farms: U.S. Milk Production by Farm Size**



Source: National Agricultural Statistical Service, http://www.nass.usda.gov/.

3 U.S. Dairy Policy

One can characterize the U.S. dairy policy as having two primary objectives: (i) providing a price support level to establish a minimum level of farm income and (ii) incorporating counter-cyclical price stabilization systems to ensure an orderly supply and marketing of farm milk. These two goals are the main driving forces for the Dairy Product Price Support Program, the Milk Income Loss Contract (MILC) program and the use of classified pricing of milk under the Federal Milk Marketing Order (FMMO) system.[4]

To understand the agricultural policy, it is essential to understand the concept of parity. If the purchasing power of money received for a unit of milk is equal to that in the base period, which is 1910-1914, then milk is priced at parity. The minimum price of milk used for manufacturing purposes has been supported continuously since the passage of the Agricultural Act of 1949. This Act required the Secretary of Agriculture to support the prices received by dairy farmers for manufacturing-use milk at between 75 and 90

[4] For a review of the classified pricing of milk under the FMMO system, refer to Jesse and Cropp (2008). For a description of the U.S. dairy industry and recent historical dairy policy, refer to Blayney et al. (2006) and Blayney (2002).

percent of parity. The specific parity level within this range was determined by forecasting the adequacy of future milk production in fulfilling market needs. Using assumed yields and manufacturing costs, the support price for manufacturing-use milk was converted into a price per pound of cheddar cheese, butter and non-fat dry milk. The Commodity Credit Corporation (CCC) stood ready to purchase unlimited quantities of cheddar cheese, butter and non-fat dry milk at these prices to keep the price of manufacturing-use milk from falling below the support level. The assumption was that if cheese, butter and non-fat dry milk plants received these prices, then they would be able to pay dairy farmers at least the support price for their milk. In 1973, the minimum support level was raised from 75 to 80 percent of parity. The Agricultural and Consumer Protection Act of 1977 maintained the minimum support level of 80 percent of parity through April 1, 1981 and required that the support price be adjusted semi-annually (October 1 and April 1) to reflect changes in the Index of Prices Paid by farmer operators. Inflation during the 1970s and changes in the farm productivity resulted in the support price increasing from US$4.28 per hundredweight[5] (9.72¢ per liter) on October 1, 1970 to US$13.10 per hundredweight (29.76¢ per liter) 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 US$2 billion annually.

This surplus situation led to a major change in the support program. The Agriculture and Food Act of 1981 removed the support level from parity. The support price would now be tied to both the level of CCC purchases and the 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 US$10.10 per hundredweight (22.94¢ per liter) support price through 1995. The Federal Agricultural Improvement and Reform Act of 1996 increased the support price to US$10.35 per hundredweight (23.51¢ per liter) for 1996, with subsequent reductions of US$0.15 each January 1 to US$9.90 (22.49¢ per liter).

With the passage of the 2008 Food, Conservation and Energy Act of 2008 (2008 Farm Bill) the former *milk* price support program was renamed the *dairy product* price support program.[6] The purchase prices for butter, non-fat dry milk and cheese are unchanged from the levels existing prior to its passage but they are no longer linked to a specific manufacturing milk price.

Federal Milk Marketing Orders (FMMO's) represent a set of regulations that address the specific nature of milk as a flow commodity, which means that it is produced every day and must move quickly to market. Fresh milk cannot be stored for a significant length of time without processing, which implies that day-to-day milk supply may not be balanced

[5] Hundredweight (cwt) equals 100 lbs or 45.36 kilograms. In terms of volume, that equals 44.01 liters of milk.

[6] For a review of the dairy sub-title of the 2008 Farm Bill, refer to Jesse, Cropp and Gould (2008).

with demand. Furthermore, in the absence of any regulation, 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 the Agricultural Marketing Agreement Act of 1937. Under the current FMMO system, the primary milk producing areas in the U.S. are divided into 10 regions, and minimum prices to be paid to farmers for their milk are based on the utilization of that milk and the composition of each operator's farm milk. Each dairy farm operator in a particular marketing order obtains the same uniform price for his milk, where this milk's value is determined by a valuation of the milk's components such as protein, milkfat, non-fat solids, etc.[7]

In recent years, the market price of manufacturing milk has been much higher than the US$9.90 support price. Seeking to provide counter-cyclical support without inducing a new wave of misplaced investments in excess capacity, the Federal government enacted a new policy tool starting in December 2000 and is referred to as the Milk Income Loss Contract (MILC) program. This program provides payments to dairy farm operators to partially reimburse their forgone income when the price of milk used for bottling purposes (Class I) falls below a predefined level.[8] Payments to individual producers are limited by the amount of payment associated with 2.985 million lbs. The current version of the MILC program established via the 2008 Farm Bill modifies the previous version in that: (i) it ties the price that triggers an MILC payment directly to feed costs, (ii) raises the pay out percentage to 45 percent of the difference between the target and the actual Class I mover from the previous 32 percent and (iii) increases the covered milk to 2.985 million lbs from the previous 2.4 million lbs/cap.[9]

4 Study Objectives

There is continuing pressure by various farm groups to attempt to solve the chronic problems in the U.S. dairy industry represented by greater milk price variability, inability to generate positive returns at the farm level, increasing role of dairy exports as an important market for U.S. dairy products, etc. As such, it is important for analysts and policy-makers to obtain an estimate as to how responsive dairy producers are to changing economic and technological conditions. The examples of previous research used to examine supply response in the U.S. dairy sector include LaFrance and deGorter (1985), Chavas and Klemme (1986), Thraen and Hammond (1987), Chavas, Jesse and Krauss (1990), Chavas and Krauss (1990), Yavuz et al. (1996) and USDA (2007). These analyses

[7] It should be noted that California, which produces more than 21 percent and Idaho that accounts for 6 percent of the U.S. milk supply, are not part of the Federal Milk Marketing Order system and possess their own minimum classified pricing rules.

[8] Although the MILC trigger price is based on the Class I price mover, the MILC payment is applied to all milk regardless of use and regardless of whether this milk is produced under the FMMO system or a state-based pricing system.

[9] For an overview of the MILC program, refer to Jesse, Crop and Gould (2008). A spreadsheet model comparing the previous MILC program to the version established by the 2008 Farm Bill can be found at: http://future.aae.wisc.edu/collection/software/MILC_simulation_07_08.xls. A spreadsheet model used to estimate the Feed Cost Adjuster of the MILC can be found at: http://future.aae.wisc.edu/collection/software/milc_cost_adjuster.xls.

are limited in that they are either fairly dated or do not account for the dynamics that are inherent in the dairy herd expansion/contraction process.

The above overview of the dairy industry points to a changing industry, as represented by reduced dairy operations of larger size, the changing nature of the U.S. dairy policy and pricing, production of new types of dairy products, etc., with much of the adjustments occurring since previous analyses were undertaken so they may no longer reflect the industry's supply characteristics.

The present study will incorporate data encompassing the 1975-2007 period and provide an update of the model originally developed by Chavas and Klemme (1986). This study has three main objectives: (i) to quantify the current supply structure of the U.S. dairy industry; (ii) to gain insight into the impacts of technological changes that have occurred over the last 25 years; and (iii) based on (i) and (ii), to generate forecasts of the long-run milk supply response to price changes and possible future technological advancements.

5 Description of an Econometric Model of U.S. Milk Supply

The econometric model adopted here has a general structure of the national model of U.S. milk supply used by the Dairy Division of the Agricultural Marketing Service of USDA when examining the impacts of changes in FMMO pricing regulations, enactment of major dairy policy changes, etc. (USDA, 2007). That is, similar to USDA (2007), we start by assuming that the total U.S. milk production (MILK) is the product of the number of milk cows in the U.S. dairy herd (COW) and the average yield per cow (YLD). Given that our model is annual in nature, we have:

$$\mathrm{MILK}_t = \mathrm{COW}_t \times \mathrm{YLD}_t \tag{1}$$

Where t represents the year.

Following Chavas and Klemme (1986) and Chavas and Krauss (1990), we extend the USDA specification by explicitly accounting for the dynamics of the U.S. dairy herd size as it is impacted by both producer culling and replacement decisions as well as by the biological characteristics of dairy herd replacements.[10] The understanding of biological and economic decisions governing the dairy herd dynamics can best be exploited by separately examining the determinants of herd size (COW) and yield (YLD) via the use of two separate stochastic regression models.

The herd size specification used here is based on the underlying dairy cow biology. The reproductive cycle of a typical dairy cow is 14 months, where 9 months is the length of pregnancy and 5 months is the current industry average period between freshening

[10] For a more complete description of the underlying biological and economic models, refer to Chavas and Klemme (1986).

(giving birth to a calf) and start of the next pregnancy. Cows produce milk from the initial birth to approximately two months prior to next birth, at which time they are removed from the milking herd to rest before the next delivery. Newborn calves take approximately 9 months to reach the weight of 500 pounds, which the USDA considers as replacement heifers given that they have not yet calved. Heifers are impregnated at 15 months of age and thus give birth when they are approximately 2 years old.

For our current model, a replacement heifer in period t (HEF_t) is a female calf of at least one year of age at the beginning of the year and it is expected to enter the herd before the end of the year. Upon first calving, a replacement heifer is then considered to be a dairy cow and part of the dairy herd.

While the maximum biological age of a cow is about 20 years, intensive milking and frequent calving make cows susceptible to various diseases. Although those health problems are mostly treatable, they tend to make the economic life of the cow much shorter than the maximum possible physical age. When culled from the herd, a dairy cow is typically sold for slaughter. The age at which a cow is removed from the herd depends on a number of factors including expected future productivity, current and expected milk, feed and slaughter prices, improved yield potential of cow replacements and current/expected replacement heifer costs.

We can describe the U.S. dairy here not only by its size but also with respect to the distribution of cows across different age classes since a particular cow can produce milk over a number of annual cycles. Both these characteristics are determined primarily by the timing of culling and cow replacement. For the present study, 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, which implies a maximum economic life of 11 years. During the year t, a particular dairy cow belongs to a particular age class (AGE) where $i = 0,\ldots, 9$. In other words, AGE represents the number of years a cow has been in the milking herd in year t. When AGE is zero that means we are referring to a replacement heifer which is yet to enter the dairy herd.

We assume that each year a dairy farm operator makes a decision as to how many cows within each of the 9 productive age classes will be kept in the herd for another year. We represent the decisions by survival rates, $S_{t,i}$ defined as the probability that in year t a cow in the i^{th} productive age class will survive (i.e. stay in the herd) one more year. Using the logistic functional form, we specify the survival rate as:

$$S_{t,i} = \frac{1}{1+e^{Z_{t,i}\beta}}, \quad \left(i = 0,\ldots,9\right) \quad \left(t=1975,\ldots, 2007\right) \tag{2}$$

where $Z_{t,i}$ is a vector of explanatory variables reflecting the state of technology, economic conditions, age class at the time of selection decision and β is a vector of coefficients to be estimated. Note that $S_{t,0}$ represents the survival rate of replacement heifers that have not yet entered the milking herd. Also, $S_{t,9}$ is forced to be zero, i.e. all cows that have completed 9 years in the dairy herd are culled at the end of the period.

The number of cows in the i^{th} productive age class is determined by the product of the number of replacement heifers *i* years ago and retention rate, R_{ti}, which is the product of survival rates in the past *i* selection decisions and can be represented via the following:

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

where j is an index used to access previous years and age class survival rates. For example, suppose we want to calculate the retention rate for cows that are entering the 3^{rd} age class in 1990. Via (3) we have the following: $R_{1990,3} = S_{1987,0} \times S_{1988,1} \times S_{1989,2}$.

Total herd size (COW) can be represented as the sum of cows in each of the nine productive age classes. We can thus specify the stochastic herd size equation via the following, where we recognize the relationship between heifers in previous years and the current herd productive age class structure:

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

where HEF_{t-i} are the number of heifers i years prior to year *t* and e_t is a stochastic error term. We can incorporate the definition of age-specific retention rates from (3) and modify (4) to the following:

$$COW_t = \left(\sum_{i=1}^{9} HEF_{t-i} \left[\prod_{j=1}^{i} \left(\frac{1}{1 + e^{Z_{t-j,i-j+1}\beta}} \right) \right] \right) + e_t \tag{5}$$

Note that with (5) we can predict not only the number of cows in the dairy herd but the distribution of cows across productive age class.

The complement to the survival rate is the age-specific culling rate k_{ti}, which is defined as the proportion of the i^{th} productive age class removed from the herd at the end of year *t*.

$$k_{ti} = 1 - S_{t,i} \tag{6}$$

As stated previously, replacement decisions describe the selection of female calves to become replacement heifers. Underpinning the modeling of the replacement decision is a representation of the probability of a cow successfully calving and that calf surviving until 1 year old. We represent this probability via the following logistic relationship

$$\Gamma_t = \frac{1}{1 + e^{W_t \gamma}} \tag{7}$$

where W represents a vector of exogenous variables hypothesized to impact calving/survival probability. This implies that the number of heifers available to the dairy herd in the period *t* can be represented via the following:

$$HEF_t = 0.5\left\{\left(COW_{t-2} + HEF_{t-2}\right)\times\frac{1}{1+e^{W_t\gamma}}\right\}+\varsigma_t \qquad (8)$$

where ς is a stochastic error term. Note that in the above we use the value 0.5 given that for a majority of our study period, the use of sexed semen was not technologically possible.[11] Thus we assume that half of the newborn calves will be male animals and cannot be used as a cow replacement. In the above, we depart from Chavas and Klemme (1986) and adopt the specification of Schmitz (1997), where we model the 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, thus the inclusion of HEF_{t-2} in (8).

Equation (5) provides the model used to predict the number of cows in the dairy herd. However, we still need Equation (8) for long-run dynamic forecasts of the dairy herd size. The additional information needed to generate an estimate of the U.S. milk production is an estimate of the average annual per cow productivity. Following USDA (2007), Chavas, Jesse and Krauss (1990) and Chavas and Klemme (1986), we represent milk yield as stochastic, where the impact of a number of exogenous variables on yield is captured via the following simple linear form:

$$YLD_t = X_t\alpha + \nu_t \qquad (9)$$

where X is a vector of exogenous variables impacting milk yield and ν is a stochastic error term.

Given the above, our econometric model is represented by the stochastic regressions contained in (5), (8) and (9). We use the estimation strategy of Chavas and Klemme (1986), where each equation is estimated via single equation least squares. Equations (5) and (8), given their non-linear (in parameters) structure, are estimated using single equation non-linear least squares procedures. Given the above non-linear specifications, the marginal effects of changes in the exogenous variables will have the opposite sign of the estimated model coefficients.

6 Description of Data Used in the Analysis

The above econometric model is estimated using the annual data that encompasses the 1975–2007 period. Given the lags involved in the herd size, equation data encompassing the 1966–1974 period was also used in the estimation. While data available go back to

[11] For a discussion of the sexed semen technology, refer to Overton (2007).

1951, the year 1975 was chosen as the starting period to reduce the impact of a 1970 USDA change from age-based to weight-based system to categorize dairy cows and replacement heifers. Since that change artificially reduced the published number of dairy cows by 2 million from 1969 to 1970, we use the 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 a change in the heifer definition. Chavas and Klemme (1986) did not account for this change, which may be one of the reasons why our model shows a substantially better fit in heifer equation than their study.

Table 1 provides a representation of the categories of exogenous variables used in the three stochastic equations. In each equation, there are three types of exogenous variables: (i) those that capture the state of technology and herd structure; (ii) variables used to describe the economic environment; and (iii) a set of dummy variables that identify time periods during which unique government policies impacting the dairy industry were in effect. Table 2 provides the definitions of the variables that comprise the above categories.

Table 1 **Listing of Explanatory Variables by Category**

Dependent Variable	**Explanatory Variables**				
	Symbol	**Category**			
		Technology, Herd Structure Dynamics	**Prices**		**Government Policy**
COW_t	$Z_{t-j,i-j}$ $i = 1,..,9$ $\forall\ i,j = 1,...,i$	AGE = i - j	MP_{t-j}	MP_{t-j} x AGE	$Dum84 = \begin{cases} 1, & \text{if } t-i+j = 1985 \\ 0, & \text{otherwise} \end{cases}$
			FP_{t-j}	FP_{t-j} x AGE	
		$\frac{HEF_{t-j}}{COW_{t-j}}(AGE)$	SP_{t-j}	SP_{t-j} x AGE	$Dum86 = \begin{cases} 1, & \text{if } t-i+j = 1987/1988 \\ 0, & \text{otherwise} \end{cases}$
HEF_t	W_t	T = t - 1974	MP_{t-1}	MP_{t-3}	$Dum84 = \begin{cases} 1, & \text{if } t = 1985 \text{ or } 1986 \\ 0, & \text{otherwise} \end{cases}$
			FP_{t-1}	FP_{t-3}	
			FP_{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	T = t - 1974	MP_t	MP_{t-1}	$Dum84 = \begin{cases} 1, & \text{if } t = 1984 \\ 0, & \text{otherwise} \end{cases}$
		YLD_{t-1}	FP_t	FP_{t-1}	

Technological Progress Variables

The level of technology is modeled in the heifer equation (8) by a simple trend variable. The non-linear functional form used in (8) allows for the impact of technology to change over time. For example, due to improved technology, attempts to fertilize cows may be more successful, calf death rates could be reduced and more calves selected to be grown into replacement heifers may actually be completing the process without severe health problems that might induce involuntary culling.

In the yield Equation (9), we assume that the trend variable primarily reflects genetic improvements of dairy cows. Indeed, we will see that this trend variable is the major determinant of changes in per cow productivity.

Herd structure is incorporated in the herd size equation by two variables. First, as noted above, inclusion of the productive age class variables (AGE) allows survival rates to differ across the 9 productive age classes. Secondly, we include as an exogenous variable lagged replacement ratio, which is defined as the ratio of replacement heifers to dairy cows. A higher replacement ratio implies that more heifers are ready to enter the herd and, consequently, more of the older, less productive cows can be removed from the herd without reducing herd size. We assume the effect of a higher replacement ratio will be different for different productive age classes. As such, we interact the AGE and associated replacement ratio, $\frac{HEF_{t-j}}{COW_{t-j}}(AGE)$ variables. Following Chavas and Klemme (1986), we assume that a higher heifer availability does not influence the retention rate of cows that have just entered the herd (AGE, i.e. productive age class of replacement heifers is zero).

Table 2 **Descriptive Statistics for Model Variables**

Variable	Units	Description	Mean	St. Dev.	Min.	Max.
COW	1,000 Head	Dairy cows, USDA Cattle inventory, January 1	10,552	1322	8,990	14,452
HEF	1,000 Head	Replacement heifers, 75 percent of published cattle inventory data for January 1 "500+ lbs heifers"	3,066	203	3,442	4,770
YLD	lbs/year	Yield per cow	15002	2,999	10,293	20,267
FP	US$2007/cwt	Feed cost, 16 percent protein dairy feed	24.58	7.04	13.25	35.21
MP	US$2007/cwt	All milk price. MILC payment added for 2001-2008	9.23	3.55	4.87	19.33
SP	US$2007/cwt	Omaha/Sioux Falls boning utility cow slaughter price	81.91	29.27	40.08	153.62
AGE_{ij}	#	Age of the i^{th} productive age class at the 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	Mil lbs	Total U.S. Milk production, calculated as identity: PROD=COW x YIELD	149,516	17,929	116,235	185,078

Technological progress is also reflected in the use of the 0.5 multiplier in the heifer 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 a decline in the price of sexed semen services, wider adoption of that technology is likely to push this parameter into the range of 85-90 percent (Overton, 2007). While we fix this parameter when estimating the model, by increasing its magnitude in some simulated scenarios we are able to make a first step at investigating the impact of sexed semen adoption on the price responsiveness of the U.S. milk supply.

Economic Environment

Given that we focus only on the supply side of the dairy industry, we include three sets of prices that characterize the dairy sector economic environment: all-milk price (MP_t), feed price (FP_t) and slaughter cow price (SP_t). All prices are given in real terms by dividing by the CPI. In contrast to Chavas and Klemme (1986), who use milk/feed and slaughter/feed ratios as principal economic variables, we allow for the data to determine the relative milk-feed and slaughter-feed price impacts. The milk, feed and cow slaughter prices used in the model are all expressed in 2007 US$. For milk price, we use the published U.S. all milk price per cwt published by the USDA. Starting in December 2001, the Milk Income Loss Contract (MILC) program was adopted as a federal dairy policy. The MILC program was included in the Farm Security and Rural Investment Act of 2002 and is a type of target price/deficiency payment program that makes a direct payment to dairy producers when milk prices fall below a specified trigger level. This program includes a payment feature that limits the amount of a producer's annual milk sales eligible for MILC payments. The 2002 farm bill authorized the MILC program through September 30, 2005. Subsequently, the MILC program has been reauthorized through August 31, 2007 under the Agricultural Reconciliation Act of 2005 and further by the 2008 Farm Bill.[12] We account for the MILC program by calculating the average annual per cwt payment and adding this value to the U.S. All-Milk price for years 2001-2007.

We define feed price (FP) in a manner similar to that of USDA (2007) and Chavas, Jesse and Krauss (1990), who use the costs of a 16 percent protein dairy feed ration to represent feed price. Based on USDA's formulation, this ration is composed of 41 percent corn, 8 percent soybeans and 51 percent dry alfalfa hay. This is the assumed ration used in the feed cost adjuster to determine the level of deficiency payment under the current MILC program. For slaughter cow price (SP), we use the Omaha and Sioux Falls boning-utility grade cow slaughter price.

We assume that culling decisions are made in such a fashion to equalize the present value of expected future earnings from milk sales with the current salvage value, as represented by the slaughter cow price. Schmitz (1997) uses a linear forecast of next period prices as a way to model rational expectations. However, when a dairy farmer makes a decision, he needs to take into account expected prices, not just in the next period, but over the entire potential remaining lifetime of a cow. Hence, using last available (observed) prices in our model should not be interpreted as an assumption of naive adaptive expectations, but as modeling marginal impact of last available information.

Changes in the economic environment will influence each productive age class differently. When production is more profitable, the herd manager might decide to replace more of the older, less productive cows. The opposite holds as well, i.e. when prices make for less lucrative production, it will not be profit-maximizing to invest in

[12] For a description of the current version of the MILC program, refer to Jesse, Cropp and Gould (2008) and to http://future.aae.wisc.edu/milc.html.

more productive but expensive replacement heifers, and that might be reflected in higher retention rates of older cows.[13] To capture the differentiated effect of price changes upon each productive age class, we use price-age interaction variables (i.e. MP_{t-j} x AGE) in the herd size Equation (5).

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

While the yield equation with its simple linear structure may seem the most straightforward to interpret the effect of our exogenous variables, it is in fact the case that the impact of prices on yield is theoretically the most challenging to understand as there are possibly two opposing effects on yield that occur with any price change. One of the most important day-to-day decisions a dairy farm operator must make is the composition of the feed ration. With increases in milk prices or decreases in feed costs, the producer would like to increase the feed ration to capture this opportunity for additional income. In addition, these relative price changes impact the desired herd size of many producers. That is, dairy farm operators with relatively high milk prices would like to enlarge their herds and those farm operators who intended to exit the industry may decide to postpone retirement. Should there be a 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 the older cows and thus increasing the overall herd size, however, will increase the share of less productive animals in the herd in the short-run, and will work to decrease yield, even while increasing milk production. This implies that there can be no clear theoretical prediction as to the expected impact of changes in the economic environment to immediate changes in yield. The two effects may cancel each other out, or either can dominate the other. Within one period after the change has occurred, we would expect the short-term adjustments to be completed, which is why we include milk and feed prices in period *t-1* as explanatory variables. We further try to capture the adjustment

[13] It should be noted that following Chavas and Klemme (1986), we model the U.S. dairy herd as one representative herd in a competitive market. For this specification we cannot account for the importation of dairy replacement heifers. Thus we assume that heifers are not traded and can only be grown. This assumption justifies the exclusion of the live replacement heifer price as one of the economic variables in the heifer equation.

dynamics in the yield equation by including the lagged yield as one of the explanatory variables.

Policy Environment

The third category of explanatory variables used to explain herd size and heifer availability are a set of dichotomous variables used to capture the impact of changes in government policies. There are three federal programs that we include in our model. The variable *Dum84* captures the effect of the Milk Diversion Program enacted from January 1984–March 1985. Under this program, participating producers were eligible for payments of US$10 per hundredweight on the difference between their "base period" sales and actual sales, provided their actual sales were between 5 and 30 percent below base (Lee and Boisvert, 1985; Boynton and Novakovic, 1984). This policy was part of the comprehensive package of measures that sought to decrease the chronic surplus of milk production. Although the program was in effect for 14 months, since it is expensive to keep idle cows on feed, we assume that culling and replacement decisions in that year where 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.

The Milk Diversion Program was complemented by a much more thorough Dairy Herd Termination Program (DTP), active from September 1986 to the end of 1987 and accounted for by the variable *Dum86*. Under the DTP, participating farmers were paid to slaughter or export their entire dairy herds. In addition, participants agreed to remove themselves and their facilities from dairy production for at least 5 years.

Identification of our Dependent Variables

As noted above, there are four dependent variables in our model. The dairy herd size, COW_t is composed of all dairy cows as of the January 1 USDA inventory estimate of the number of milking cows. The annual per cow milk yield (YLD_t), the second dependent variable, is obtained from the National Agricultural Statistical Service. The number of replacement heifers (HEF_t) was obtained by multiplying USDA's January 1 Cattle inventory data for "500lbs + dairy heifers" by the factor 0.75. Heifer calves that are between 8 and 12 months of age on January 1, when the survey is done, weigh between 500 and 800 lbs and are included in the USDA estimate 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 one year old should be treated as replacement heifers according to the 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 a case for a different specification of this correction procedure, using inventory accounting to arrive at the numbers of heifers that have actually entered the herd in the period *t*. Schmitz (1997) follows such an approach in his research on the beef industry, and calculates beef replacement heifers as a sum of the annual beef herd size change and the number of beef cows that have been slaughtered or have died. Employing a similar procedure to the dairy sector will not help reduce noise in heifers data, as the estimated number of dairy cows slaughtered is much less reliable than the estimates applied to beef cattle due to, among other things, biased accounting procedures in those slaughterhouses which primarily service the beef industry.

7 Estimation of an Empirical Model of U.S. Milk Supply

The estimation period for the model spans the 33 year period of 1975-2007. We estimate each of the stochastic equations separately using least squares methods. The yield equation is estimated by OLS while the equations for herd size (Eq. 5) and heifers (Eq. 8) are estimated via non-linear least squares using the Gauss-Newton (GN) algorithm. Given the degree of non-linearity of these last two equations, the sum of squared errors (SSE) function is likely not globally convex over the parameter space. This implies that there are potentially numerous local SSE minima. To insure that the algorithm converges to a local minimum, we estimated Eq. (5) and (8) 4,000 times, each time using a different randomly drawn vector of starting values for the coefficients. From the vector of solutions, our estimate of the global minimum is then identified by a simple ranking of empirical SSE values.

Given the non-linear nature of Eq. (5) and (8), one must rely on asymptotic properties of the estimated parameters to determine their distributional characteristics. In small samples such as the one used here and when the model is highly non-linear, the applicability of the large sample theory may be inappropriate and any estimate of asymptotic standard errors of the coefficients must be taken with caution. One clear indicator that the large sample theory performs poorly for a certain model would be that bootstrap estimates of the confidence intervals of coefficients are much different than the confidence intervals based on the asymptotic theory.

To determine if our model possesses such a discrepancy, we use a residuals-based bootstrapping procedure to simulate the data generating process and obtain alternative estimates of parameter standard errors. The bootstrapping procedure simulates alternative samples, assuming the estimated coefficients are the true unknown parameter values. Alternative dependent variable vectors are generated by using random draws from a joint empirical distribution of estimated residuals. Specifically, the following bootstrapping procedure is used:

(1) Estimate the three stochastic equations using least squares procedures. From these regressions, evaluate equation specific errors and concatenate these error vectors to form the (T x 3) error matrix.

(2) Use the estimated coefficients to predict the number of heifers, cows and yield in 1975, which is the first estimation year. Randomly draw a row from the above matrix of estimation residuals and add the residuals to the associated predicted values of the dependent variables to generate simulated values for our dependent variables: heifers, cows and yield.

(3) Obtain a simulated value for heifers, cows and yield in 1976:
   a. Predict the number of cows in 1976, using simulated cows and heifers in 1975 as explanatory variables in the herd size equation. For all other explanatory variables (prices, technology, policy dummies), use actual data for 1976. In similar manner, predict 1976 heifers and yield.
   b. Add randomly chosen residuals to obtain simulated values for the three dependent variables as was done in (2).

(4) Repeat step (3) for the remainder of the sample, always using previously obtained simulated values for previous years whenever lagged dependent variables or their ratios enter as explanatory variables in any equation.

(5) Steps (1)-(4) create one sample from the assumed data generating process governing herd dynamics. Re-estimate the cows, heifers and yield equation using the simulated sample, and store the results of the estimation.

(6) Repeat steps (1)-(5) 4,000 times.

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

8 Overview of Estimation Results

Estimated coefficients and asymptotic standard errors for the three stochastic equations are presented in Table 4. Remember in the heifer Equation (10.1) the explanatory variables are used within a "survival rate" function, which represents the probability of a heifer being freshened and allowed to enter the milking herd. With the exponential function in the denominator, the marginal effect of a change in a regressor on the survival probability will have the opposite sign to the estimated coefficient. Given its definition, the marginal effect on the heifer "culling rate", which is one minus the heifer survival rate, will have the same sign as the estimated coefficient. In terms of interpreting the herd size equation, we need to remember that the number of cows of a particular age in the herd is the product of the number of heifers in previous years times the combined probability of surviving to the current time period. Similar to the heifer equation, these survival probabilities are specified as being logistic. Thus the *culling rate* marginal impacts of a change in an exogenous variable will have the same sign as the estimated coefficient in the cow survival function.

Table 3 **Estimated Model of U.S. Dairy Supply (1975-2007)**

$$HEF_t = \frac{1}{2}\left(COW_{t-2} + HEF_{t-2}\right) / \left[1 + \exp\left(\underset{(0.150)}{0.758} - \underset{(0.003)}{0.019}\,T - \underset{(0.030)}{0.136}\,Dum84 + \underset{(0.003)}{0.126}\,Dum86 \right.\right. \tag{10.1}$$

$$\left.\left. - \underset{(0.006)}{0.016}\,MP_{t-1} + \underset{(0.008)}{0.022}\,FP_{t-1} + \underset{(0.001)}{0.003}\,SP_{t-1} - \underset{(0.005)}{0.011}\,MP_{t-2} + \underset{(0.008)}{0.014}\,FP_{t-2} - \underset{(0.001)}{0.003}\,SP_{t-2}\right)\right] \quad R^2 = 0.883$$

$$COW_t = \sum_{i=1}^{9} H_{t-i} / \left\{\prod_{j=1}^{i}\left[1 + \exp\left(-\underset{(0.789)}{2.694} + \underset{(0.079)}{0.151}\,Dum84 + \underset{(0.031)}{0.231}\,Dum86 - \underset{(0.057)}{0.063}\,MP_{t-j}\right.\right.\right. \tag{10.2}$$

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

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

$$YLD_t = \underset{(1381.36)}{5093.17} + \underset{(50.77)}{204.89}\,T - \underset{(142.29)}{463.26}\,Dum84 - \underset{(15.16)}{17.75}\,MP_t + \underset{(34.35)}{28.29}\,FP_t + \underset{(15.23)}{38.08}\,MP_{t-1} \tag{10.3}$$

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

$$PROD_t = YLD_t \times COW \tag{10.4}$$

Note: Asymptotic standard errors are in parenthesis. The variables are defined as follows:

HEF_t = the number of replacement heifers intended to enter the herd in the current year and calculated as 75 percent of heifers over 500lbs. on dairy farms on Jan. 1 (1,000 head); COW_t = the annual average number of dairy cows on dairy farms (1,000 head); MP_t = U.S. All-Milk price plus MILC payments (US$/cwt); FC_t = the value of a 16 percent protein dairy ration (51 percent corn, 41 percent hay, 8 percent soybeans) (US$/cwt); SP_t = Omaha/Sioux Falls slaughter cow boning/utility price (US$/cwt); T = time trend (1=1975; 2=1976; etc.); AGE = (i - j + 3) where i = 1,...,9 j = 1,...,9; $DUM84_t$ = a dichotomous dummy variable identifying the Milk Diversion Program active in 1984; $DUM86_t$ = a dichotomous dummy variable identifying the Whole-herd Buy-out Program active in 1986-87; YLD_t = production per cow (lbs);
$PROD_t$ = U.S. milk production (billion lbs).

Given the above, we would thus expect to see the milk price coefficient in Equations (10.1) and (10.2) to be negative, as we anticipate the two culling rates to be negatively related to milk price. The higher the milk price, the greater the expected profitability associated with milk production and a reduced incentive for culling cows, *ceteris paribus*. Conversely, our initial hypotheses are that higher feed and slaughter prices will have a positive impact on the culling rate for heifers and milk cows.

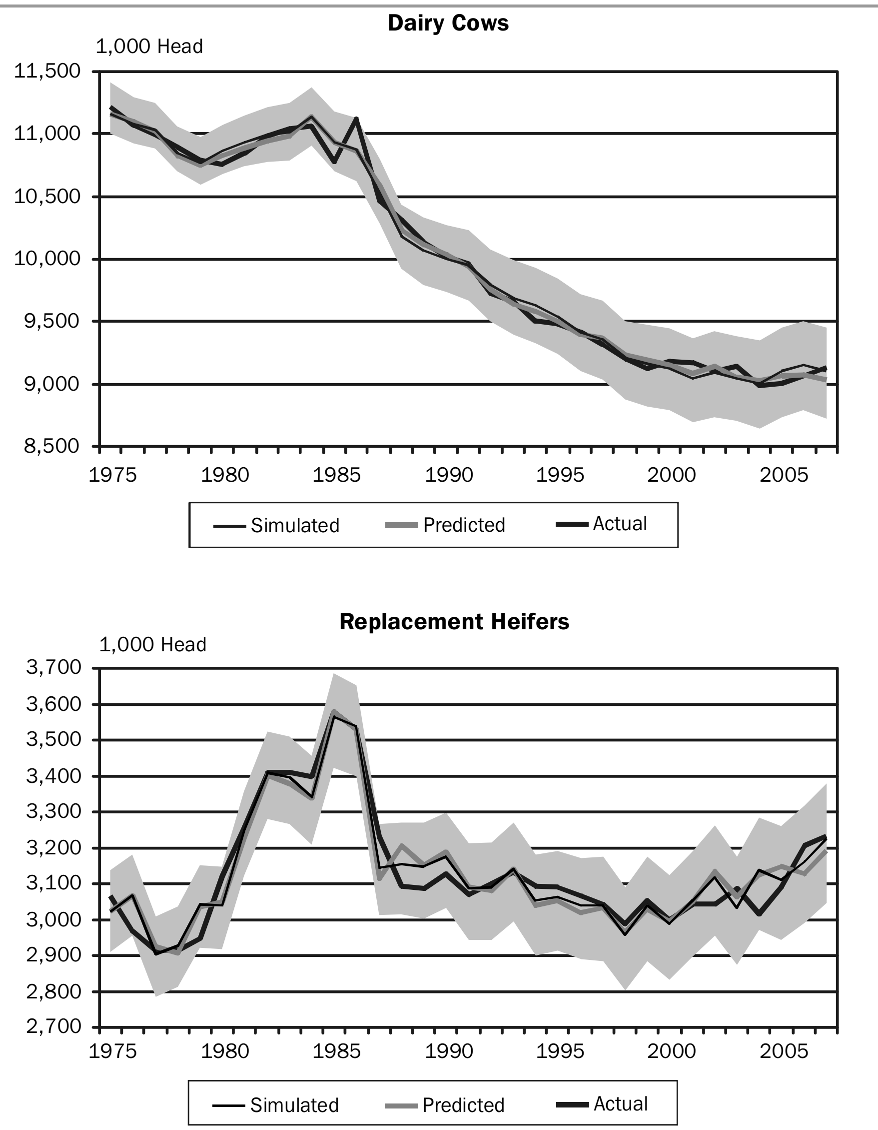
As reviewed above, the Milk Diversion and Whole Herd Buyout dairy policies had as their primary objective the reduction in the U.S. herd size. We would expect a positive effect of these policies on the culling rate and, therefore, expect positive coefficients on the associated policy-related dummy variables in the herd size equation. Even though it decreased the number of dairy cows, the Milk Diversion Program did not have a requirement that producers permanently leave the dairy industry. Accordingly, we anticipate that with a reduction in the milking herd there would be a subsequent increase in the demand for replacement heifers. Thus we anticipate the sign of the estimated coefficient associated with the variable *Dum84* to be negative in the heifer equation.

Estimating the above three equations by least squares, we obtain a high degree of the in-sample prediction accuracy. The cow equation has a maximum absolute prediction error of 2.2, 3.6 in the heifer equation and 2.5 percent in the yield equation. In Figure 4, we provide a representation of the actual, static prediction and dynamic simulations of the number of heifers and size of the U.S. dairy herd. In addition, we provide a 95 percent confidence interval of these variables based on our bootstrapped results.

In the heifer equation, all estimated coefficients were found to be statistically significant at the 5 percent confidence level. In the herd size equation, the milk price and interaction of the milk price and cow age were found not to be individually significant, so we tested for a joint significance of the coefficients for average and age-specific impacts of milk price.[14] Results of individual Wald tests show that the combined average and age-specific impacts of the prices of milk and feed are highly significant. We did not find any significance for the cow slaughter price. This last result is not surprising given that over the last 25 years, yield per cow has doubled. This implies that the salvage value of cow represents a much smaller fraction of the present discounted value of future earnings from the cow. Consequently, culling decisions were found to be influenced by the milk price to a larger degree than the cull cow price.

[14] A comparison of the bootstrapped and Information Matrix based parameter standard errors showed little difference in the interpretation of the individual coefficient statistical significance.

Figure 4 **Comparison of Actual and Predicted Number of Dairy Cows and Replacement Heifers**



Source: National Agricultural Statistical Service, http://www.nass.usda.gov/ and authors' calculations.

Since all parameters in the heifer and cows equation are in the exponent of the logistic function, it is not straightforward to determine the magnitude of price change impacts on short-term culling rates. To address this issue, in Table 4 we present a 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 a 10 percent change in prices. For example, the culling rate for cows in the second productive age class, which corresponds to 3 years of age, is 17.3 percent. This implies that of the cows that survived the first year in the herd, 17.3 percent will be culled in 2007. An increase in the milk price by 10 percent over the average milk price for 2007 (19.13 US$/cwt) would decrease the culling rate by 0.9 percent to 16.4 percent. Both the Wald test and tests for the significance of the marginal impacts of prices on culling rates indicate that our model shows a statistically significant impact of the milk price on cow herd dynamics.

Table 4 **Predicted Marginal Impact of Prices on Cow Culling: 2007**							
Age (i + 2)	**Cull Rate (k_{ti}) %**	**Marginal Price Impact**					
		$\Delta k_{ti} / \Delta MP_{2007}$		$\Delta k_{ti} / \Delta FP_{2007}$		$\Delta k_{ti} / \Delta SP_{2007}$	
		Value	**S.E.**	**Value**	**S.E.**	**Value**	**S.E.**
2	12.6	-0.8	0.5	0.9	0.3	0.0	0.2
3	17.3	-0.9	0.4	0.7	0.2	0.0	0.1
4	23.4	-0.8	0.2	0.4	0.2	0,0	0.1
5	30.7	-0.5	0.4	-0.2	0.2	-0.1	0.1
6	39.2	-0.2	0.9	-0.9	0.4	-0.2	0.3
7	48.4	0.3	1.5	-1.7	0.7	-0.3	0.5
8	57.7	0.7	2.0	-2.4	0.9	-0.3	0.6
9	66.5	1.0	2.3	-2.9	1.2	-0.4	0.7
10	74.2	1.2	2.4	-3.1	1.3	-0.4	0.8

Note: These are the effects of a 10 percent increase over the 2007 level.

9 Evaluation of Long-Run Price Effects on U.S. Milk Supply

To evaluate the long-run (10 year) impacts of price changes on the U.S. dairy herd, we address the following question: *If real prices remain constant over the next ten years, what will be the impacts on the U.S. milk production?* To address this question, we evaluate 10 year production profiles under the following 3 price scenarios:

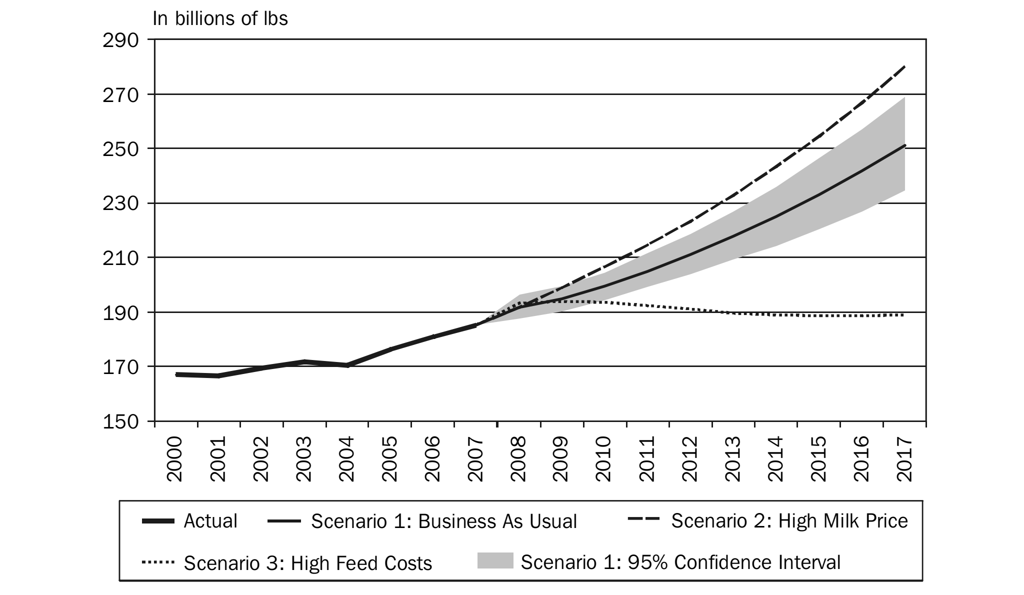
(i) *Scenario 1*: The All Milk, Slaughter and 16 percent Dairy Feed Prices remain at their average 2005-2006 levels;

(ii) *Scenario 2*: Prices stay at their 2007 levels. It should be noted that 2007 was a relatively good year for the dairy industry in spite of high grain prices. The U.S. All-Milk price averaged US$19.14/cwt, the average corn grain price was US$3.39/bu and the average soybean price was US$7.74/bu.

(iii) *Scenario 3*: To investigate the long-term impact of extremely high feed costs under this scenario, we assume that prices over the next ten years are constant at the following level: Corn – US$5.50/bu, Soybeans – US$12.00/bu, Alfalfa Hay – US$165.00/ton, while the price of milk stays as high as it was in 2007.

Under all scenarios, cow productivity improvements are assumed to follow the structure represented by the estimated yield Equation (10.3) shown in Table 3. Figure 5 is used to portray milk production under the above three scenarios over the 2008-2017 period. In addition, we have plotted the bootstrapped confidence interval for Scenario 1.

Figure 5 **Impact of Alternative Price Scenarios on Future U.S. Milk Production**



It is not surprising that the optimistic milk price environment represented by Scenario 2 generates a large increase in milk production relative to the base case of Scenario 1. Starting with 2010, the estimated production under Scenario 2 is above the upper level of the 95 percent confidence interval of the estimated production under Scenario 1. By 2017, the estimated production under Scenario 2 is 4.2 percent above the upper confidence level. Similarly, the high feed cost scenario, Scenario 3, generates substantially lower milk production levels starting with production in 2010. In 2010, milk production under Scenario 3 is 0.4 percent less than the lower confidence interval boundary obtained for the milk production under Scenario 1. This relative decline increases to -19.4 percent by 2017.

Given the above results, we evaluate long-run herd size and milk production elasticities to milk, feed and slaughter price changes. We evaluate these elasticities via the following procedure:

- i) Choose the starting year.
- ii) To obtain point estimates of the elasticities, we use the estimated parameters obtained from the regression models.
- iii) To obtain the confidence intervals of these elasticities, we randomly draw from the bootstrapped parameter estimates along with the estimated residual matrix. Thus we account for uncertainty in our estimated coefficients and the presence of information uncertainty.
- iv) Set prices for the next 10 years to be the same as in the starting year. This is referred to as the *base scenario*. The 10-year period that begins with the starting year is referred to as the *simulation period*.

v) Undertake dynamic simulations of the number of cows, heifers and the total milk production for each year of the simulation period.

vi) Identify the exogenous variable for which elasticities are to be calculated (e.g. all-milk price, slaughter cow price, cost of a 16 percent dairy ratio).

vii) Increase the above variable in the initial year to be 10 percent higher than observed. Keep other prices unchanged.

viii) Set prices for the next 10 years to be the same as in the starting year but at the higher level, i.e. alternative scenario.

ix) Simulate the number of cows, heifers and the total milk production under the alternative scenario in each year of the simulation period, using the same matrix of forecast errors as in base scenario simulations.

x) For each year in the simulation period, calculate the arc elasticity of the number of cows, number of heifers and U.S. milk production under the alternative and base scenarios.

xi) Calculate elasticity confidence intervals by repeating (i) – (x) 1,000 times.

In Table 5, we provide point estimates of the milk and feed price elasticities, along with the limits that define the 2.5 (Low) and 97.5 (High) percentiles of the empirical distribution of bootstrapped long-run elasticities average over the 1978-1982 and 2003-2007 periods.

There are several patterns to notice in Table 5. First, regardless of the starting year, it was not surprising that long-run elasticities are much higher than short- and intermediate-run elasticities given the dynamics of the dairy herd adjustment process. Second, by comparing elasticities across different starting periods, we see that the price-responsiveness of the dairy industry has not increased over the last 25 years.

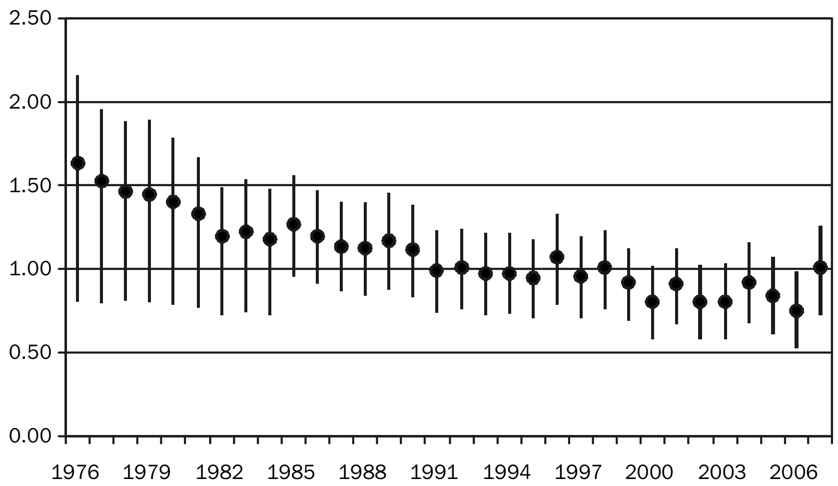
One might expect that with better genetics, improved heifer management and larger farms the industry would be likely to react to prices more quickly than thirty years ago, when the majority of dairy operations were small or medium-sized.

Table 5 **Short-Run and Intermediate-Run Elasticities of U.S. Dairy Supply to Milk and Feed Price Changes**

	Years Since Price Change (j)														
1978-1982	1			3			6			10			25		
	Elas.	Low	High	Elas.	Low	High	Elas.	Low	High	Elas.	Low	High	Elas.	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		
	Elas.	Low	High	Elas.	Low	High	Elas.	Low	High	Elas.	Low	High	Elas.	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

To investigate this issue further, in Figure 6 we plot the 10-year herd-size elasticities, calculated for each year in the sample. This figure is used to display the 10-year elasticities depending on the year of price change initiation as well as the 5 percent confidence interval of these elasticities. While the mean of the elasticity shows a clear downward trend, bootstrapped confidence intervals are large enough that the point estimate for the 10-year elasticity in 2007 falls within the confidence interval for elasticity calculated in 1980, and vice versa.

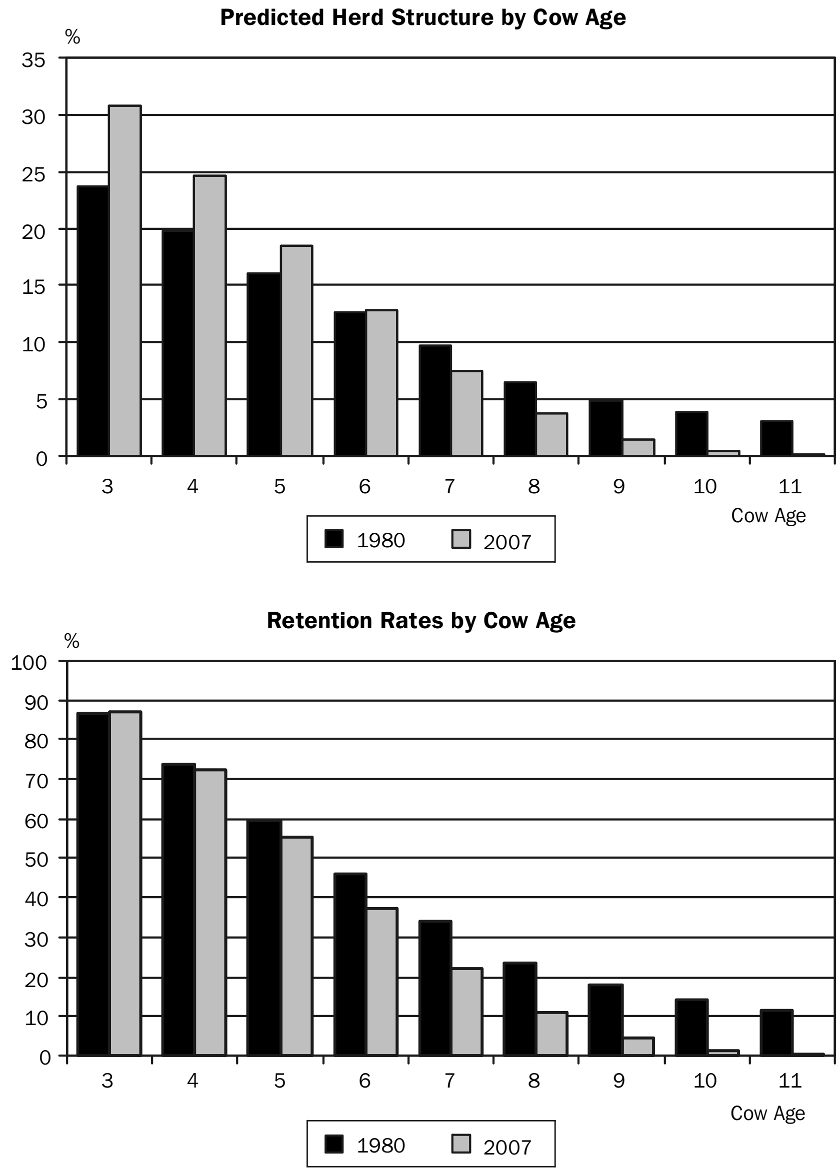
Figure 6 **Estimated 10-year Supply Elasticity and Associated Confidence Interval**



We would like to formally test whether price-responsiveness has changed over the 1980 – 2007 period. We do this by comparing the empirical distribution of the 10-year elasticities for herd size, number of heifers and total milk production for 1980 and 2007 for both the all-milk and 16 percent dairy feed prices. To undertake this test, we simulate the distribution of differences between 10-year elasticities for 1980 and 2007. If null hypothesis is correct, than the distribution of differences should be roughly centered around zero. We reject the null hypothesis if the number of simulations in which 2007 is less price-responsive than 1980 is less than 5 percent of the total number of bootstrap simulations. Using this test procedure, 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 the elasticity of the number of heifers to the feed price was higher in 1980, while results, for the number of cows and total milk production, are inconclusive.

The conclusion that long-run elasticities have indeed declined is unexpected. To explore the potential causes, we exploit the fact that while we only observe the 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 7, we plot the distribution of herd by cow age and retention rates for each age class for two time periods, 1980 and 2007.

Figure 7 **Predicted Herd Size and Retention Rates by Cow Age**



The implication from this figure is that while the cow retention rates for cows age 3-5 (first three lactations) have remained the same over these two time periods, older cows are significantly less likely to be kept in the herd. For dairy operations, the major adjustment to changes in the economic environment is accomplished via herd culling and replacement activities. When dairy farm operators experience positive changes in the economic environment and wish to expand their herd, they can (i) keep current milking cows in the herd longer while maintaining the previous number of replacement heifers entering the herd or (ii) increase the share of female calves that are grown into replacement heifers and ultimately added to the herd. It is important to notice that the younger the herd, the higher is the replacement ratio needed to keep the herd size unchanged.

We argue that a reduction in the long-run price responsiveness is the result of increases in involuntary cull rates that make it harder for dairy farm operators to increase the retention rate of cows in the process of adjustment to favorable changes in the economic environment. Hadley, Wolfe and Harsh (2006) report that in herds participating in the Dairy Herd Improvement program (DHI), health culls, i.e. culls induced by health problems of a cow, constitute 79.5 percent of all culls. If the share of health culls in all culls has increased over time, that would imply that culls are starting to be less of an economic decision, and are increasingly a consequence of biological constraints. Furthermore, health culls are a greater constraint on expanding than on reducing the herd, for a farmer can always decide to increase the cull rate up to 100 percent, but health culls represent the lower bound beyond which culls cannot be easily reduced.

10 Comparing U.S. and Croatian Dairy Sectors

Our research focused solely on the U.S. dairy sector, but to make this paper more interesting for the Croatian audience, we include here a brief comparison of U.S. and Croatian dairy sectors. It is interesting to list some basic descriptive statistics of the dairy industry in Croatia. In Croatia, there were 32,000 milk farms in 2008, with 177,000 dairy cows and a yearly production of 650 million liters of milk (Grgić, 2008a). That translates to the average farm size of 5.53 cows, and yield of 3,672 liters/cow per year (8,200 lbs/cow). To gain some idea how that compares to the United States, first notice that the entire U.S. has a little more than double the number of farms in Croatia, although its population is 70 times higher. In terms of productivity, the average Croatian farm lags 40 years behind the U.S. farm, where 3,600 liters/cow was achieved in the mid-1960s. However, the Croatian dairy sector is undergoing major restructuring, and the number of farms has been almost halved from 59,000 to 32,000 in the last 5 years. Changes in the industry structure are shown in Table 6.

Table 6 **Distribution of Croatian Dairy Farms by Size**

Cows on farm	**2003**		**2007**	
<3	44,562	75.76%	17,963	56.2%
4-8	11,875	20.19%	9,163	28.67%
9-14	1,521	2.58%	2,354	7.36%
15-27	666	1.13%	1,684	5.27%
>27	191	0.32%	795	2.48%
Total	58,815	100%	31,959	100%

Source: Based on Grgić (2008b).

All this tells us that the Croatian sector is decades behind the U.S. sector analyzed in this paper. While that should make us careful in drawing direct analogies, it should also allow this paper to serve as a valuable "look into the future" should Croatia and the EU decide to follow the U.S. in the pursuit of a similar agricultural policy.

11 Conclusions

The econometric analysis contained in this study is an update of Chavas and Klemme (1986). We felt that an update was required given the significant structural and policy changes that have occurred in the U.S. dairy industry since their manuscript was first published. We find the model performs very well with respect to in-sample simulations. Our results, as represented by various price elasticities, differ significantly from those obtained from the original model application.

Several conclusions emerge from our study. First, given the large difference between short-run and long-run responses of production to price changes, policy-makers are cautioned not to discard or vindicate any policy changes based solely on how industry reacts after one or two years after the changes are introduced. What may in the short run seem like a minor impact that does not disturb market equilibrium can indeed lead to large production surpluses after more time has passed and the dairy herd size has had adequate time to adjust to the new policy environment.

Second, a focus on yield in genetic selection, while rational from the perspective of a single producer, may have unfavorable side-effects on an industry level. Reduction in the long-run price responsiveness of supply will occur if the length of economic life of a cow is reduced due to health reasons, implying that more replacement heifers are required to maintain a stable herd size.

Finally, a wide adoption of sexed semen in replacement heifer breeding is likely to play a major role in how the industry evolves. We have undertaken some preliminary analyses of the impact of increasing the proportion of female dairy calves by adjusting the 0.5 constant in the heifer equation. Our initial analyses suggest that the impact on the industry supply curve will be to increase the All-Milk price responsiveness.

The obvious shortcoming of this model is that it assumes market prices to be predetermined. We are currently extending this model to incorporate its dynamic framework into a partial equilibrium model of the dairy sector similar to USDA (2007). The main advantage of such a model will be that not only will we be able to evaluate the impacts of specific policy changes on the level of milk production but we will be able to examine the policy and technological change impacts on equilibrium market prices. We will then use this model to examine the impact of: changes in MILC program rules (i.e. higher payment rate, higher covered milk production limits, changes in feed cost adjuster); implementation of alternative supply management programs (i.e. CWT, the Holstein Association plan, the Milk Producers Council plan and a USDA Whole Herd Buyout program); and the impacts of the adoption of alternative technologies (i.e. sexed semen, reduced use of rBST and an increased use of rotational grazing).

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