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Can the Small Dairy Farm Remain Competitive in U.S. Agriculture?

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Abstract

The cost of milk production by farm size was decomposed into frontier and efficiency components with a stochastic cost curve using data on 755 USA dairy farms from the year 2000. The estimated frontier function is much flatter than the composite cost curve, and although the frontier cost of production decreases with farm size, that cost reduction is not as pronounced as a cost curve that includes inefficiency. The higher cost of production of many smaller farms is caused by inefficiency. The 50-cow farm has a frontier cost of production of $10.05 and an inefficiency cost of $10.27 for a composite cost of $20.32. In contrast, the 1,000-cow herd has a frontier cost of production of $9.27 and an inefficiency cost of $2.82 for a composite cost of $12.09. The implication is that the efficient 50-cow farm is competitive with the average 1,000-cow farm, but not with the efficient 1,000-cow farm.

Introduction

A common topic of conversation heard in rural coffee shops, agricultural colleges, and on Capitol Hill in Washington, DC, involves the future of the small dairy farm in the United States. A large number of small dairy farms have ceased operation in traditional dairy areas, and many wonder how many more small dairy farms will be lost. These discussions center on whether and how the small dairy farm can survive. Some believe there is no future for the small dairy farm in U.S. agriculture since its cost of production per hundredweight of milk produced is thought to be higher than the cost of production per hundredweight of milk on larger farms. Indeed, engineering cost studies of dairy

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production have shown lower unit costs with larger production units (Matulich). In a competitive market like milk, the survival of the small dairy farm hinges upon whether those farms are competitive with larger dairy farms, and their long-run survival depends upon having low cost of production.

That there has been a reduction in the number of small dairy farms is undeniable. During the decade of the '90s, the number of dairy farms in the United States decreased 42 percent, from 180,640 farms in 1991, to 105,250 farms in 2000. This reduction came almost exclusively from the decline in the number of small dairy farms. Farms with fewer than 100 cows decreased from 159,866 operations in 1991 to 84,410 operations in 2000, while the number of farms with over 100 cows increased slightly over that period, from 20,774 to 20,840 operations (Blayney).

Since low cost of production is critical for dairy farm survival, our research estimates the cost of milk production by farm size using individual farm production data from the year 2000 National USDA Dairy Production Practices and Costs and Returns Survey. However, there are two components to the cost of production for an individual farm. The first is the lowest cost for the specific technology and practices that a farmer can use at a given farm size. This can be referred to as the best practice or frontier cost curve. The second component of cost is how efficient an individual farm is in using the techniques available for a given farm size. Costs greater than the best practice cost can occur if a farmer is inefficient in using best practice techniques. In this research both of these cost components were modeled and estimated as a function of the number of cows. The modeling procedure allows both frontier and efficiency cost components to vary by farm size.

Whether high cost of production is due to inefficiency or a higher cost, frontier has significant implications for government policy addressing the small farm. If high cost of production on smaller farms is due to a higher cost frontier, then to make small farms competitive would require research to devise and design technology that is suitable for small farms. If instead high cost is due to inefficiency, and not a high cost frontier, then current technology exists that would allow small farms to be competitive with larger farms. Educational programs would be necessary to ensure that small dairy farms use more efficiently the technology currently available to them at their respective size.

Even if a passive policy position is taken so that little or no intervention is undertaken to influence farm survival by farm size, knowledge of the source of high cost and the distribution by farm size is useful for industry decision-makers. If some dairy farms are inefficient, for instance, but a certain number are efficient, that knowledge can be used to forecast the number of surviving dairy farms by farm size by region in a competitive dairy market. That would assist industry participants in making long-term processing plant investment decisions.

Review of Literature

Cost of production studies have a long tradition in the agricultural economics literature. Through the years the cost of production by farm size has been estimated for various commodities and regions of the U.S. (Madden; Stefanou and Madden). Recent cost studies of dairy production have found lower unit costs with larger production units (Bailey et al.). These procedures estimate average cost of production by farm size without estimating the distribution of costs around these averages by farm size. Our research models and estimates the distribution of costs around the means by farm size. The deviations are assumed to be due to inefficiency and data error. Inefficiency is estimated as a function of farm size, and a frontier cost function of efficient farms is simultaneously estimated as a function of farm size.

Tauer used this approach to estimate the cost of production for New York dairy farms for the production year 1999. His study data mostly included farms over the size range of 50 to 500 cows, so prediction outside this range is not feasible. Farm observations were not randomly selected so self-selection bias may exist in these results. The results are also only applicable to New York.

Tauer estimated that farms with an average of 50 cows had average costs of $16.95 per hundredweight, but $3.34 of that was due to inefficiency. If those farms had all been operated as efficiently as the most efficient 50-cow farm, average costs would have been much lower at $13.61, although this was still $0.58 higher than the average costs for the efficient 500-cow farm. Although the 500-cow herd has an efficient cost of production of $13.03, the average 500-cow farm also has an inefficiency cost component of $0.83. This implies that the efficient 50-cow farm with a cost of $13.61 has lower costs than the $13.86 cost of the average inefficient 500-cow farm. Efficient small farms have lower costs than does the average large farm, but the efficient large farm still has slightly lower costs. These results clearly show that most of the observed high cost on New York small dairy farms is due to inefficiency. Efficient small dairy farms have costs only slightly greater than efficient larger farms, and their costs are lower than those of inefficient large farms.

Alvarez and Arias estimated economies of size of Spanish dairy farms assuming fixed managerial ability of each farm operator. They modeled and estimated managerial ability as the technical efficiency of individual farms, with managerial ability and farm size separately impacting the average cost curve. Since they had panel data, they were able to determine unique farm results. Size elasticity averaged –0.28 with a minimum value of –0.60 and a maximum value of 0.15. The elasticity of managerial ability on average cost averaged –0.26 with a range from –1.12 to 0.82.

Method

The procedure used is typically referred to as a stochastic cost function. Aigner, Lovell, and Schmidt; Battese and Corra; and Meeusen and van den Broeck introduced stochastic frontier production functions. They decomposed the typical error term of a regression model into an efficiency component plus a measurement error, and used maximum likelihood estimation to estimate simultaneously the parameters of the production function as well as efficiency and measurement error. The approach is now routinely used to estimate not only production but also profit and cost functions. More recently, beginning with Kumbhakar, Ghosh, and McGuckin, and Battese and Coelli, the efficiency component has also been simultaneously estimated as a function of causation factors. In our research both the frontier and the efficiency components were modeled and estimated as a function of dairy farm size in order to decompose cost of production by size into both frontier cost and inefficiency components.

An average cost curve of a dairy farm is estimated as a function of cow numbers on the farm and an error term,

(1) $Cost/Cwt_i = f(Cows_i) + \varepsilon_i$,

where $Cost/Cwt_i$ is the cost of production per hundred weight of milk on farm i, $Cows_i$ are the number of cows on farm i, and the ε_i error term for a single farm observation i, can be broken into a stochastic term, v, due to data error, and an efficiency term, u, such that $\varepsilon_i = v_i + u_i$. The efficiency term, u, is further specified as a function of cow numbers,

(2) $u_i = g(Cows_i)$.

The stochastic term, v, is modeled as a normal distribution, iid $N(0,\sigma^2)$, while the efficiency term, u, is modeled as a truncated positive half-normal distribution with mean specified by equation (2), $N^+ (g(Cows_i), \sigma^2)$. This allows the stochastic term for an individual farm observation to be either negative or positive, but the expected efficiency term will be equal to or greater than zero. Estimation of this model is by maximum likelihood. Since a stratified random sample was used, a weighted maximum likelihood model was used with the weights applied outside the likelihood function. The maximum likelihood function and derived test statistics are reported in the software manual for LIMDEP, the software package used for estimation (Greene).

Individual farm cost inefficiency was computed as $E[u|v+u]$ derived in Jondrow et al. and implemented in LIMDEP. This provides the cost inefficiency of individual farms expressed in dollars per hundred weight of milk produced. These cost inefficiencies were then regressed on cows by weighted OLS using the function g to quantify the relationship between farm size and cost inefficiencies. Frontier cost of milk production per hundredweight of milk by farm size was obtained by inserting cow numbers into function f. Total cost of production by farm size was constructed as the sum of frontier cost and cost inefficiency. Total cost of production was then sorted from low to high and used to determine which farms would survive at various long-run milk prices.

Note that the cost curve is estimated to be a function of the number of cows rather than output, whereas cows are typically considered an input in the dairy production process. However, cow numbers are commonly used in the USA as a measure of dairy farm size. An advantage of using the number of cows as a proxy for quantity of output is that the number of cows on the farm is predetermined in the short run (exogenous), and thus not stochastic as milk output would be. Stochastic output could be correlated with the error term. The correlation between milk output and the number of cows on a farm is 0.97 for the data used so the number of cows serves as an excellent proxy for output. The important advantage of using cows as the single variable in both the frontier and efficiency components of the model is that it allows comparing frontier cost and cost inefficiency with a single common consistent measure.

Total cost of production per hundredweight of milk was further decomposed into variable and fixed costs of production, and separate functions were estimated for each cost component, permitting determination whether efficiency differs by farm size when inputs are variable versus fixed in nature. Variable costs include those inputs which can easily be adjusted over the calendar year, and include such inputs as feed, worker labor, and energy. Fixed costs, in contrast, include those inputs that are not easily changed as more or less milk is produced over the calendar year. Fixed costs include capital and operator’s labor. Frontier cost curves estimated for the various cost components also provide information concerning the degree of economies or diseconomies in fixed versus variable inputs. Although economies and diseconomies of size are believed to result mostly from fixed factors of production, it is possible that variable costs display a corresponding or contrary pattern to the fixed cost frontier.

Data

Data are from the Dairy Production Practices and Costs and Returns Report (Agricultural Resource Management Survey Phase II, commonly referred to as ARMS). These data were collected by a survey jointly administered by the National Agricultural Statistics Service and Economic Research Service of the USDA for dairy production during the calendar year 2000. The target population was farms milking 10 or more cows in the 22 major dairy states. The sample is a multi-frame, probability-based survey in which farms are randomly selected from groups of dairy farms stratified by farm characteristics such as farm size, with greater coverage in the primary dairy production states. The survey design allows each sampled farm to represent a number of farms that are similar, the number of which being the survey expansion factor. The expansion factor, in turn, is defined as the inverse of the probability of the surveyed farm being selected. The survey collects data to measure the financial condition and operating characteristics of farm businesses, the cost of producing agricultural commodities, information on technology use and management practices, and the well-being of farm operator households. On-farm enumerators collected the data using a 36-page survey instrument.

Dairy costs and returns for each farm have been calculated by the USDA and are used to compute the cost of production per hundredweight of milk sold. Three cost measures were computed for each farm. These are variable or operating cost, fixed cost, and then total cost. These are farm costs and reflect the cost of producing not just milk, but other commodities and spent cows. To calculate the total cost of producing milk per hundredweight of milk, sales of livestock and other non-milk income were subtracted from total farm costs, which were then divided by the hundredweight of milk sold. This approach presumes that the primary operation on these farms is milk production and the cost of producing other income is equal to that income. On average, 88 percent of the total revenue on the farms surveyed was from milk sales. Total cost per hundredweight of milk was separated into variable and fixed components.

There were 872 original observations. Total costs per hundredweight of milk ranged from 2 negative values to 17 observations with costs over $100 per hundredweight of milk. Scrutiny of these farms revealed a variety of possible reasons for these extreme cost values. Some had large cattle sales, probably reflecting a profitable cattle-breeding program. Others had extremely low production levels. Since many other reasons may also have been responsible for extreme values, it was decided to use only farms with total cost greater than $4.00 and less than $35.00 per hundredweight of milk sold. This resulted in 755 observations. New weights were computed for the maximum likelihood estimation and cumulative farm size analysis.

The average number of cows on the 755 farms was 216, with 29 farms having more than 1,000 cows. The average total cost of production per hundredweight of milk was $18.46, composed of $9.81 fixed cost and $8.65 variable cost. A plot showing individual farm observations cannot be shown given the confidential nature of the data. Yet, the relationship between total cost per hundredweight of milk sold and farm size as measured by the number of dairy cows is decreasing in number of cows but with greater variability in costs at smaller farm sizes. This supports the thesis that large firms only survive if they are efficient. Surprisingly, however, there are a large number of small farms that have total costs that are as low as or lower than the costs of many large farms.

Results

Two functional forms were tried for both the frontier function f, and the efficiency function, g. These were the quadratic specified as:

$$Cost/Cwt_i = b_1 + b_2 * (Cows_i) + b_2 * (Cows_i)^2 + \varepsilon_i,$$

and the natural log specified as:

$$u_i = a_1 + a_2 * \ln(Cows_i).$$

The best fit as determined by lowest total variance, $\left(\sigma_v^2 + \sigma_u^2\right)$, was the natural log for both the frontier function, f, and the efficiency function, g, although all four combinations generated similar quantitative results for numerical frontier and efficient costs by farm size. The estimated cost curves for variable cost, fixed cost, and total cost without inefficiency modeled in the cost curves and estimated by weighted OLS are reported in Table 1.[1] Total cost decreases with greater cow numbers, but that decrease is strictly due to a decrease in fixed costs. The ln(cow) variable is not statistically significantly different from zero in the variable cost curve, implying that the variable cost of milk production is flat at $7.86 per hundredweight of milk regardless how many cows are present in the herd. The ln(cow) variable is statistically significant in both the fixed cost and total cost curves.

[1] These coefficients are used for the starting values for the maximum likelihood efficiency estimates.

These results carry over when these three cost curves are estimated with the inclusion of inefficiency within the model, as reported in Table 2. The variable cost frontier curve is statistically flat, with no inefficiency estimated. In contrast, both the frontier fixed cost curve and the inefficiency of fixed costs decrease as cow numbers increase. Although the frontier total cost curve decreases with increasing cow numbers, that decrease is minor and not statistically significant. In contrast, the total cost curve, like the fixed cost curve, displays a decrease in inefficiency as cow numbers increase.

The composite and frontier cost curves for farm total cost are graphed in Figure 1. These are derived by calculating frontier and inefficiency cost by farm size. The estimated frontier curve is much flatter than the composite cost curve, and although the frontier cost of production decreases with farm size, that cost reduction is not as pronounced as the cost curve that includes inefficiency. Indeed, the higher cost of production of many smaller farms is estimated to be caused by inefficiency, and that inefficiency decreases as the farm becomes larger.

As Table 3 illustrates, the 50-cow farm has a frontier total cost of production of only $10.05 per hundredweight of milk, but a large inefficiency cost of $10.27.[2] In contrast, the 1,000-cow herd has a frontier total cost of production of $9.27 and an inefficiency cost of $2.82, for a composite cost of $12.09. Thus the efficient 50-cow farm has a $2.04 lower total cost than the inefficient 1,000-cow farm, but the efficient 1,000-cow farm has a lower total cost of $0.78 than the efficient 50-cow farm. The implication is that the efficient 50-cow farm is competitive with the average 1,000-cow farm, but not the efficient 1,000-cow farm. There is a future for the small U.S. dairy farm, but probably only if that small dairy farm is close to being cost efficient.

Table 4 reports these cost relationships for the fixed cost component of the farm. Cost economies exist in the frontier cost component, and inefficiency decreases with increasing cow numbers. As compared to the total cost relationships shown in Table 3, fixed cost demonstrates greater economies of size and less cost reduction with greater efficiency. It appears that both cost economies and inefficiencies occur in the fixed cost component of the dairy farm. Technologies embedded in fixed costs lower the cost of production per hundredweight of milk produced for larger farms, and those larger farms are more efficient in using that technology. There is no inefficiency estimated in the variable cost curve by farm size, but there is inefficiency in the fixed cost curve by farm size. Consequently, efforts aimed at decreasing the inefficiency of the small dairy farm should be aimed at decreasing this fixed cost inefficiency. Research efforts are needed to determine why small farms often do not efficiently use their fixed assets.

The estimated frontier cost curve can be used to predict the size of surviving farms in the long run where costs must be lower than the milk price. Essentially, any efficient size farm can survive with a milk price above $10.00 per cwt., with the efficient large 1,000-cow farm only having a $0.78 frontier cost advantage over the 50-cow farm. However, it would appear that many inefficient small farms would be lost since on average they are less efficient than the large farms. However, there are individual small farms that are very efficient and these farms would survive.

The size distribution of dairy farms that are inefficient at various long-run milk prices can be predicted by using the estimated frontier and inefficiency costs derived from individual farm observations, and then multiplying each surviving farm observation by its normalized survey expansion factor. Results are illustrated in Figure 2 where the

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[2] The alternative functional forms also produced large cost inefficiency for the 50-cow farm.

cumulative distribution of the original 755 farms is shown along with the cumulative distribution of surviving farms at long-run milk prices of $15.00 and $13.00 per hundredweight. Milk prices have averaged around $13.00 the last few years, but have often surpassed $15.00. Note that costs include both frontier cost and cost inefficiency. The results do not incorporate market equilibrium changes. If farms leave the industry, input prices will be altered, possibly changing the cost structure of various farms. However, milk prices have ranged between $13.00 and $15.00 per cwt. in recent years, with exodus of numerous dairy farms, so there might not be significant changes in input prices and costs.

This analysis of the ARMS data currently predicts an average dairy farm size in the U.S. of 125 cows.[3] At a milk price of $15.00 per cwt. the average dairy farm size would be 354 cows, and at a milk price of $13.00 the average farm size would be 313 cows. Interestingly, the results show that the impact would be to mostly reduce the number of medium-size farms. Most medium-size farms are not as efficient as the most efficient small farms, although the frontier cost of these medium-size farms is lower than that for the small farms. In contrast, very large farms have both low frontier costs and generally low cost inefficiencies. The implication is that low milk prices would impact medium-size farms the most. Many small farms would also disappear, yet many efficient small farms would survive. The large farms would mostly survive. These results support Edwards, Smith, and Peterson who find a reduction in the number of medium-size farms,

[3] This is larger than the USDA year 2000 average of 88 cows per farm. The survey data are only from farms with more than 10 cows in the 22 major dairy states, and cost outliers were removed. Thirty percent of U.S. dairy farms in 2000 had fewer than 30 cows (Blayney).

and infer a flatter herd size density compared to current densities, yet still not the bimodal size distribution many believe exist in U.S. agriculture (Wolf and Sumner).

Conclusions

It appears that both economies of size and inefficiency exist in the fixed cost but not the variable cost component of the typical U.S. dairy farm. The variable cost of producing a hundredweight of milk shows no significant economies of size, nor does variable cost show a reduction in efficiency with farm size. In contrast, the fixed cost of producing milk decreases with farm size and the farm becomes more cost efficient.

These relationships were obtained by estimating a stochastic cost curve where cost of production per hundredweight of milk was regressed on the natural logarithm of cow numbers, with cost efficiency simultaneously estimated as the natural logarithm of cow numbers. Data were from a USDA stratified random sample of U.S. dairy farms for the production year 2000.

These results imply that for the small U.S. dairy farm to become competitive with the large U.S. dairy farm requires some new technology appropriate for smaller farms. However, a much larger cost reduction on smaller farms would be possible if those farms would learn how to use the technology represented by those fixed costs more efficiently. Although new technology for the small dairy farm would be useful, it appears that current technologies are in place which would make the small dairy farm more competitive if those farms used that technology efficiently.

If dairy farms do not become more efficient, a projection of farm size distribution using estimated frontier costs and cost inefficiencies show a trend toward larger average size for dairy farms in the U.S. Many small inefficient dairy farms will disappear, but other more-efficient small dairy farms will survive. Many medium-size farms will fail, but most large dairy farms will remain in operation.

Table 1. Estimated Cost Curves for U.S. Dairy Farms with no Inefficiency Modeled, Year 2000.

	Variable Cost	*Fixed Cost*	*Total Cost*
Intercept	7.86	26.32	34.18
Coeff./S.E.	(13.91)	(29.00)	(29.03)
Prob. ≠ 0	0.00	0.00	0.00
Ln(cows)	0.11	-3.49	-3.38
Coeff./S.E.	(0.82)	(-16.87)	(-12.61)
Prob. ≠ 0	0.41	0.00	0.00
Adjusted R^2	0.00	0.27	0.17

Dependent variables are cost of producing 100 pounds of milk.

Table 2. Estimated Cost Curves for U.S. Dairy Farms with Inefficiency Modeled, Year 2000

	Variable Cost	*Fixed Cost*	*Total Cost*
Frontier Cost Component			
Intercept	5.41	6.57	11.06
Coeff./S.E.	(8.12)	(9.56)	(5.72)
Prob. ≠ 0	0.00	0.00	0.00
Ln(cows)	0.1524	-0.5912	-0.2595
Coeff./S.E.	(1.02)	(-4.95)	(-0.83)
Prob. ≠ 0	0.31	0.00	0.41
Inefficiency Component			
Intercept	-681.18	33.64	32.92
Coeff./S.E.	(-0.09)	(4.04)	(5.37)
Prob. ≠ 0	0.93	0.00	0.00
Ln(cows)	-16.74	-6.97	-6.02
Coeff./S.E.	(-0.04)	(-8.59)	(-5.81)
Prob. ≠ 0	0.97	0.00	0.00
Standard Deviations			
σ_v	1.86	0.95	2.35
σ_u	41.37	6.35	7.29

Dependent variables are total cost of producing 100 pounds of milk.
Inefficiency is modeled as a positive half-normal distribution with Mean = $a_1 + a_2 * \ln(\text{cows})$. The stochastic error is modeled as a normal distribution with mean = 0. Estimation by weighted maximum likelihood using 755 observations.

Table 3. Separation of Total Cost of Milk Production into Efficiency, Inefficiency, and Size Components, U.S. Dairy Farms, Estimated by Stochastic Cost Curve, Year 2000

Number of Cows	*Frontier Cost*	*Inefficiency Cost*	*Composite Cost*	*Cost Due to Size*[a]
50	$10.05	$10.27	20.32	$0.78
100	9.87	8.55	18.42	0.66
150	9.76	7.54	17.30	0.49
200	9.69	6.82	16.51	0.42
500	9.45	4.55	14.00	0.18
1,000	9.27	2.82	12.09	---

[a] Cost difference for efficient farms compared to efficient 1,000-cow size.

Table 4. Separation of Fixed Cost of Milk Production into Efficiency, Inefficiency, and Size Components, U.S. Dairy Farms, Estimated by Stochastic Cost Curve, Year 2000

Number of Cows	*Frontier Cost*	*Inefficiency Cost*	*Composite Cost*	*Cost Due to Size*[a]
50	$4.26	$8.99	13.25	$1.77
100	3.85	7.05	10.90	1.36
150	3.61	5.91	9.52	1.12
200	3.44	5.10	8.54	0.95
500	2.90	2.53	5.43	0.43
1,000	2.49	0.58	3.07	---

[a] Cost difference for efficient farms compared to efficient 1,000-cow size.

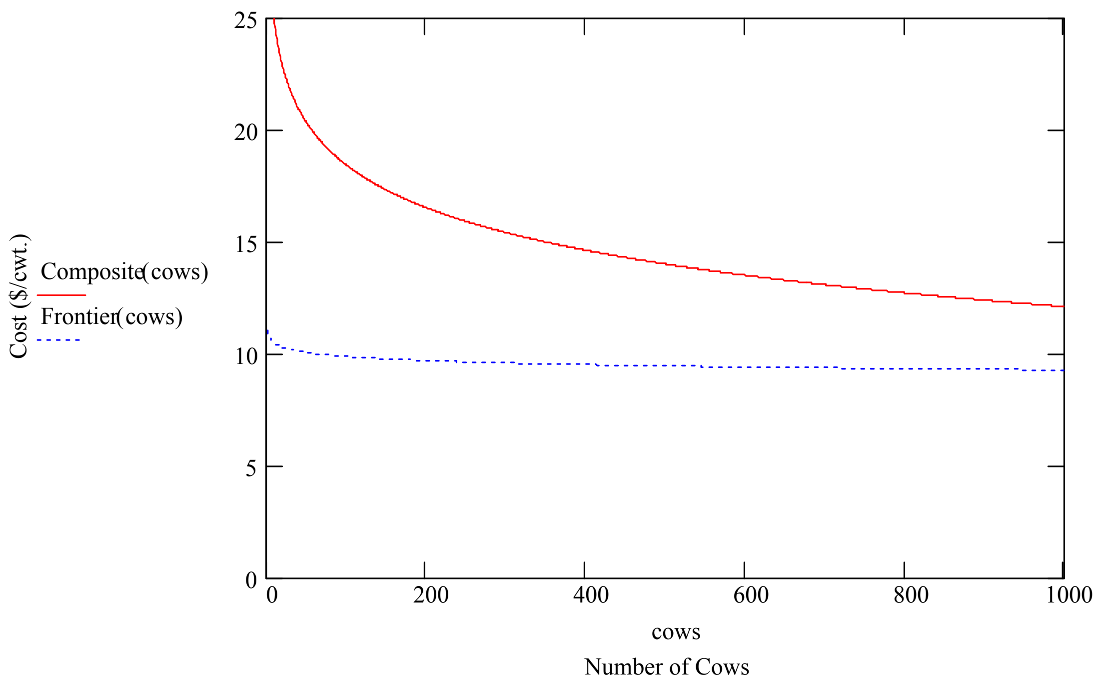

Figure 1. Composite and Frontier Cost of Production (Total Cost) per Hundred-weight of Milk Sold, U.S. Dairy Farms, Year 2000.

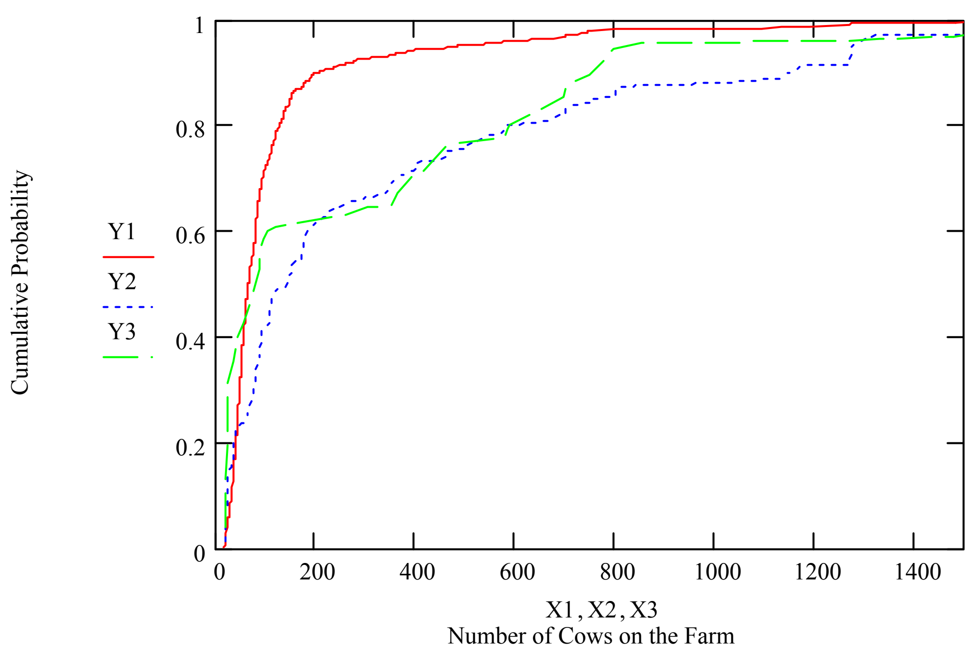

Figure 2. Cumulative Probability Distribution of U.S. Dairy Farm Size. Y1 is the current distribution from survey data, Y2 is the distribution of surviving farms at a milk price of $15.00 per cwt., and Y3 is the distribution of surviving farms at a milk price of $13.00 per cwt.

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