VALUE OF NEW TECHNOLOGIES IN DAIRY FARMING: THE CASE OF ROBOTIC MILKING

By

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Abstract

The economic value of the innovation robotic milking systems (AMS) is examined for Swedish dairy operations. A mixed integer mathematical programming model, considering crops, calving distribution, seasonality and capacity constraints of the AMS system, is developed. The marginal value of increasing the capacity of the AMS unit is found to amount to 40 - 60% of the milk revenues per cow.

JEL classification: Q12

Key words: Technology innovations; Dairy systems

Introduction

Crop production on dairy farms is generally closely linked with the dairy operation, which greatly complicates the managerial process. Feed for the dairy herd is usually produced on the farm, therefore the appropriate choice of crop mix depends on the feeding plan. Herrero, Fawcett and Dent argue that an appropriate selection of management strategies for livestock production "requires: (1) understanding of the system as a whole in its agro-ecological context; (2) understanding of the behavior of, and interrelations between, the different parts of the system;" (p.169).

Across time technological innovations along with improvements in managerial strategies have had a great impact on the dairy sector. The innovation of the bucket milking unit made it possible to increase herd size and brought the modern technology into the dairy sector. Recent technological developments in the dairy industry involve robotic milking systems, often labeled automatic milking system (AMS) (Halachmi; Lind, Ipema, de Koning, Mottram and Hermann). These technologies drastically alter the interrelations between the cropping and dairy systems at the farm level. In general the new milking systems imply a substitution of labor for capital. There are also various biological and technical implications of the new milking systems. Most important are the impacts on building design and appropriate feeding strategies, as described by Sonck, Halachmi, and Bohlsen and Artmann.

The literature cites advantages of the automatic milking systems such as an increase in milk production attributable to an increase in the average number of milkings per 24 hours (Hillerton and Winter; Erdman and Varner). A reduction in labor requirements is another advantage cited in the literature (Dijkhiuzen, Huirne, Harsh and Gardner; Berges and Veauthier). Furthermore, the new systems allow for more detailed monitoring of measurable biological parameters, which for example may signal health/disease problems in the herd (Mottram). An important feature of the AMS system is that the maximum capacity of the milking system is constrained by the functioning of the milking unit, which has implications for the effective average herd size. The capacity of the milking unit is typically invariant to season. A difference in average herd size may have implications for the economic competitiveness of the AMS system relative to conventional milking parlors in free stall barns. In a conventional parlor seasonal variations in the number of milking cows may be compensated by additional working hours. In addition, EU agricultural policy features a multitude of subsidies that are acreage and/or crop dependent or livestock head dependent, particularly in less favored areas. Hence, this set of policy interventions tend to strengthen the economic linkages between the livestock and crop enterprises on the individual farm, and thereby affect the internal cost of forage produced at the dairy farm.

So far, there has only been a few studies conducted in order to examine the economic feasibility of an automatic milking system in contrast to milking parlors in conventional free stall barns (Dijkhiuzen, Huirne, Harsh and Gardner; Bohlsen and Artmann; Cooper and Parsons). Reported studies have not taken into detailed consideration the complex interlinkages between land use, feeding plan, building capacity, capacity of the milking unit and the distribution of calvings over the year. Furthermore, these studies do not consider a detailed set of policy regulations that may affect the economic viability of the system due to for example effects upon the eligibility for subsidy payments. Finally, none of the studies examine the economic feasibility of the AMS system accounting for optimal adjustments of the calving distribution or land use.

Given the preceding discussion this study attempts to examine the economic viability of the robotic milking system for dairy operations with differences in the planning environment. The mathematical programming model that is developed accounts for the complex interaction between crop production and livestock production, considering seasonality as well as the technological and biological implications of the milking systems evaluated. Another novelty of the study is that we are able to explicitly derive the marginal value of technological improvements attributable to increasing the capacity of an AMS unit. The empirical analysis focuses on dairy farming conditions for various regions of Sweden but the model is applicable to similar problems in Europe or North America. The objectives of this study are:

- To assess the economic viability of the AMS-technology
- To examine which size categories of Swedish dairy farms, located in three different regions, are the primary beneficiaries of the AMS technology?

Model development

In order to analyze how different dairy farms achieve the maximum economic result, given some limited farm resources, a mathematical programming model is developed. The model is an extension of previous models developed by Brundin and Ekman and is based on mixed integer and linear programming. It is designed to analyze optimal production strategies at a specific farm business, considering capacity restrictions, seasonal pricing, calving interval, EU-regulations and farm specific restrictions. A detailed mathematical formulation along with a definition of parameters and variables is available as an appendix upon request. The mathematical modeling of the policy regulations relies extensively on integer linear programming. In the subsequent sections only the most important parts of the model are highlighted.

Basic structure

A general model is developed for various herd sizes of dairy farms. The farms differ in terms of tillable acreage, soil type, yields of grain and forage, climate and the eligibility for a set of subsides attributable to the Common Agricultural Policy as of 1999. Forage and grain crops are cultivated at the farm. An overview of the model structure is provided in Figure 1. Area of tillable land, area of pasture, storage capacity, number of stall-floors in the buildings for cows and heifers, capacity of the milking system, are constraints on the choice of an economically rational production plan. The farmers are assumed to maximize net farm income with a conventional milking parlor, π_{CONV} , or they maximize net farm income given that they invest in an AMS system, $\pi_{AMS.}$

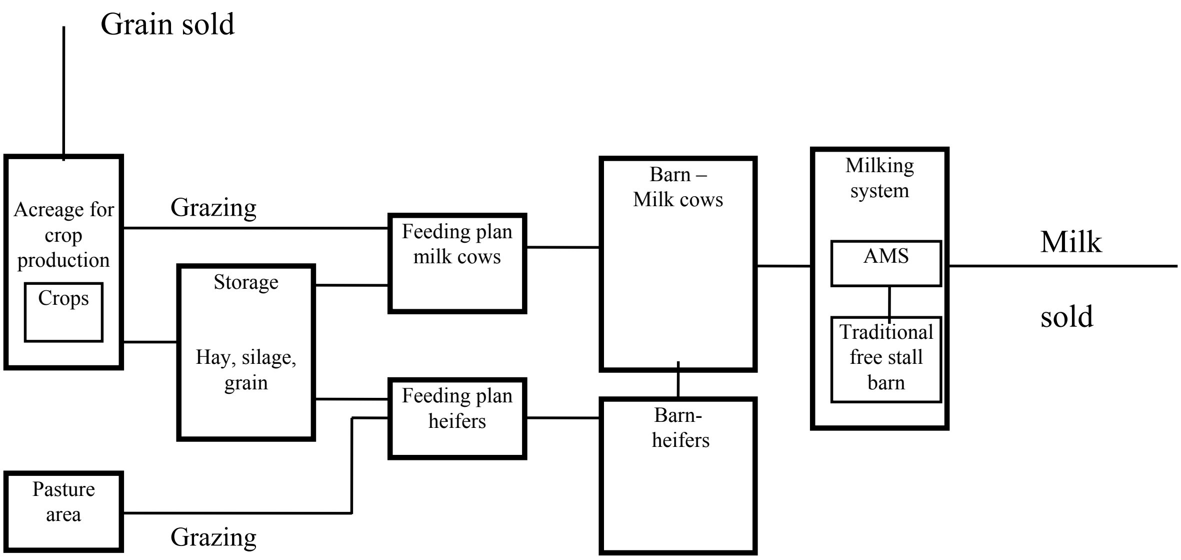

Figure 1. Schematic overview of the farming system

Milk yield and dairy herd structure

Milking is assumed to occur 2 times per day in the conventional parlor system designed for a free stall barn. This is a common system in Sweden. Given an AMS system, the cows can choose how often to be milked but the capacity of the AMS unit is a limiting factor. With an AMS system, multiple milkings (three to four per day) may be accomplished. An increase in the milking frequency may result in a higher milk yield, as shown by for example Hillerton and Winter, Ipema and Benders, and Erdmann and Varner. However, these studies also indicate that the yield increase due to multiple milkings is characterized by substantial variance. The yield increase ranges from 5 to 25 percent in these studies. Cooper and Parsons cite an increase by 10 – 15% when the milking frequency increases from two to three times per day. In this analysis it is assumed that milk production increases by 12%, due to multiple milkings. A sensitivity analysis for the case with a 6% increase is also conducted.

Milk yield per cow depends not only on the milking frequency. Milk production for a specific cow is calculated by using the Woods gamma function where α, b, and c are parameter values that determine the mathematical form of the lactation curve.

$$O = \alpha * p^b * e^{-cp}$$

O = milk yield kg ECM/day
p = number of days after calving

Data to parameterize the functions is obtained from Svensk Husdjursskötsel. An example of a lactation curve is provided in Figure 2.

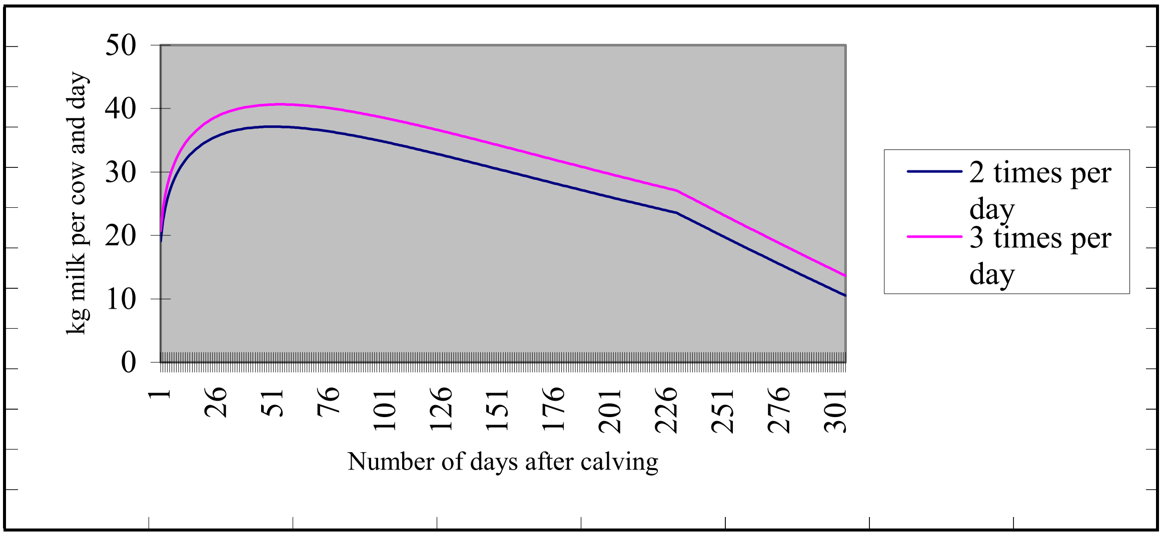

Figure 2. Lactation curves for a cow in lactation three, with January as calving month, depending upon how many times per day the cow is milked.

The herds´ total milk production in period t is given by equation (1). The decision variable $X_{l,m,f}$ denotes the number of dairy cows in lactation l, with calving period m who are fed according to feeding plan f. Consequently, $ax_{t,l,m,f}$ denotes the total milk produced in period t by a cow in lactation l, who calved in period m and is fed according to plan f. t denotes a specific time period during the calendar year that is subdivided into six periods of equal length. These parameter values are available for different lactations and calving months.

Total milk production per period t:

(1) $$M_t = \sum_l \sum_m \sum_f X_{l,m,f} \cdot ax_{t,l,m,f}$$

Transfer of milk cows to the subsequent lactation:

Equation (2) defines the transfer of cows from one lactation to the next.

(2) $$\sum_m \sum_f \phi_{l,m,t} \cdot X_{l,m,f} \geq \sum_m \sum_f \beta_{l+1,m,f} X_{l+1,m,f} \qquad \forall \text{ l, t}$$

The coefficient $\phi_{l,m,t}$ is the share of cows in lactation *l*, that calved in period *m*, that will remain in lactation *l*+1 and then calve in period *t*. The coefficient $\beta_{l+1,m,f}$ is one for $t = m$, and otherwise zero. The total number of cows in a specific lactation period, *l*+1, with the original calving period *m*, at a specific time period *t*, depends on the percentage of cows remaining from lactation *l* adjusted for the remainder parameter,$\phi_{l,m,t}$. Consequently, (1-$\phi_{l,m,t}$) represents the cows that are sent to slaughter at time *t* after having calved in period *m* and served *l* lactations. The heifers are introduced in the system as lactation, $l = 1$. The remainder parameters ,$\phi_{l,m,t}$, are obtained from Svensk Husdjursskötsel.

The lactation curves are parameterized to reflect the average milk yield of Swedish dairy cows in 1998, 8168 kg 4% milk (Svensk Husdjursskötsel, 1998). The lactation curves are calibrated by adjusting the parameter α in order to correspond to the average milk production for lactation, *l*, for Swedish cows in the year of 1998. Data is available for lactations one, two and three. Hence, lactation three is assumed to represent all the subsequent lactation numbers since in 1998 only 26% of all cows initiated the fourth lactation.

The lactation curves, designed to reflect a change in milking frequency, due to the introduction of the AMS-system are parameterized in a similar manner. In the base scenario it is assumed that the average milk yield increases with 12%.

Feeding plan

The study assumes that grazing, silage, hay, barley and wheat and various forms of concentrates are available as feeds. Ekman conducted a comparison of the economically rational choice of feeding. A feeding plan, implying a high proportion of grain was found to be the optimal choice for all categories of farms in different regions of Sweden. This latter feeding plan is used in this study for the conventional free stall system. Feeding plans for cows in each lactation and calving period are calculated using a model developed by Spörndly. Feeding plans for the AMS system account for the expected increase in milk yields. The selected feeding plan was slightly adjusted to the AMS-system with some constraints on the feed grain intake. During the summer period (May-August) grazing is available on natural and tillable pasture for youngstock, heifers and dairy cows. An illustration of a feeding plan is provided in Table 1.

Table 1. Example of a Feeding Plan for a Cow (Milked 2 times/day) in Lactation Three, with Calving Period February - March.

Feed type	Daily feed ration in kg dry matter for each period					
	Feb - March	April-May	Jun- July	Aug-Sep	Oct-Nov	Dec-Jan
Silage	7	7.5			7.5	7.5
Pasture			7.5	7.5		
Hey	1	1	1	1	1	5
Grain	7	7	6.7	5.3	2.3	
Concentrate	6.5	6.5	4.5	3.2	2.2	

Capacity of the AMS system

The capacity of the AMS-system is a crucial factor. Factors such as milking frequency, accessibility to the milking unit during the 24 hour period and the occupation rate of the milking unit are important in determining the capacity. In this study an AMS-unit is defined as a "one-box system". In the study it is assumed that the capacity of one AMS is 150 milkings per day, which is equivalent with milking 50 cows tree times per day based on a study by Gers-Grapperhaus. Accordingly, it is assumed that a multiple of AMS conducts 300 milkings, or milking 100 cows three times per day. In the conventional parlor the milking capacity is not restricted, since the milking unit is only used a few hours in the morning and the evening.

In the model, the capacity of the AMS-system is defined as the number of lactating cows that one AMS-unit is able to serve three times per day i.e. 150 milkings per day. Consequently, two AMS-units have a capacity to perform 300 milkings per day. The capacity constraint requires that the number of milking cows, $X_{l,m,f}$ in lactation *l*, with calving month *m*, feeding plan *f*, in period *t*, multiplied by the associated (and regulated) space requirements for milking cows, $\mu_{lt,m}$, do not exceed the maximal capacity, measured in number of cows milked per 24 hours (*vms*), at any time period. Hence, the marginal value of the capacity of the AMS-unit at time *t* is the shadow value of equation (3). Consequently, the marginal value of the AMS-unit may vary across season, which so far to the best of our knowledge has not yet been subject to analyses in the literature.

$$(3) \qquad \sum_{l,m,f} \mu_{l,t,m} \cdot X_{l,m,f} \leq vms \qquad \forall \, t$$

One of the more pronounced advantages of AMS is a reduction in labor used for milking. For the conventional parlor system total labor requirements are assumed to be 40 h per cow and year (Belotti, Eriksson, Fredriksson and Spörndly). As a comparison Jonsson estimated the average labor requirements to 37 hours per cow and year, not accounting for recruitment heifers. Jonsson estimates average milking time to 3.7 minutes in a parlor. If milking occurs twice a day, the milking time is estimated to 3 minutes per cow (Statens Jordbrugstekniske Försög). Bohlsen and Artmann found that the labor requirements for milking, service and supervision in a single unit AMS amounted to 1.2 minutes per cow and day. Given a lactation period of 305 days, the reduction in labor use attributable to the AMS-technology may therefore range from 12.7 to 9.15 h per cow and year. Assuming that milking time in a parlor would also include a fraction of supervision the total labor use in herds that utilize the AMS system is assumed to be 28.3 h per cow and year, which corresponds to labor savings of 11.7 h per cow. Dijkhiuzen, Huirne, Harsh and Gardner report that labor is reduced by 7.6 h per cow and year. However, estimates by Berges and Veauthier imply a labor reduction of no more than 5 h per cow and year. Due to these large differences, a sensitivity analysis for changes in labor requirements is conducted. In the sensitivity analysis a labor reduction by 5 h per cow and year is examined. The sensitivity analysis is conducted for each of the case farms.

Investments and Capital Costs

A change in milking system in an already operating free-stall barn may be associated with high rebuilding costs. Therefore, in this comparative study it is assumed that a new free-stall barn is built on each case farm independently of the milking system. The capital costs play a crucial role in the comparative analysis of the designed systems in this study. Total investments in buildings, building equipment and the milking units respectively are summarized for the parlor system and the AMS-system in Table 2 for a 60 and 120 cows herd, respectively. The information is obtained from case studies of five recently initiated dairy investment projects on farms in various regions of Sweden. All figures are adjusted to the 1999 price level. The investments in buildings are depreciated over a period of 20 years. Building equipment is depreciated over a 15 year period. The AMS-unit is depreciated over a 10 year period (Cooper and Parsons). The annuity method is utilized for allocating capital costs. The discount rate amounts to 7% following a recent study by Lagerkvist.

Table 2. Investments in SEK (thousands) for various asset categories and their percentage of the total investment. Figures are provided for the 60 and 120 cow system with a conventional parlor and an AMS system.

Investment category	Dairy herd with 60 cows in production				Dairy herd of 120 cows in production			
	Conventional parlor 2x6 Herringbone		AMS system 1 unit		Conventional parlor 2x8 Parallel		AMS system 2 units	
Building	1218.254	50.7	1107.295	36.5	2460.155	52.6	2214.590	39.4
Building equipment	684.840	28.5	624.840	20.6	1369.680	29.3	1309.680	23.3
Milking unit	500.000	20.8	1300.000	42.9	850.000	18.1	2100.000	37.3
Total	2403.094	100	3032.135	100	4679.835	100	5624.270	100

Source: Interviews with case farms; Statens Jordbruksverk, and personal communication with G. Andersson (1999)

The maintenance costs of the buildings amount to 1% of the investment where the corresponding figure for building equipment is 2%. Maintenance cost for the AMS-unit amounts to 1.9% of the investments in the AMS-unit following information provided by a manufacturer (G. Andersson, pers. communication). Parsons and Cooper use 3% in their study.

Machinery and labor

Machinery and farm labor are not explicitly considered as limited resources in the model in order to facilitate a comparison between the systems. An imputed cost of labor is used amounting to 140 SEK/hour (Agriwise). Additional labor can be acquired at the imputed rate. The rationale for introducing an imputed cost of labor is to properly account for the economic costs without unduly affecting the comparative analysis by somewhat arbitrarily determined labor constraints. Recent studies by Ramsden, Gibbons and Wilson, and Valencia and Anderson indicate that labor constraints have a large impact on the optimal production plan for a dairy farm. The approach chosen is therefore in accordance with Cooper and Parsons where differences in labor use between the systems are valued in alternative use.

The farms are assumed to have a set of base machinery that is independent of whether forage or grain is grown (tractor, plough, harrow etc). Capital and operating costs for special machinery required for forage such as mower conditioners, balers etc are taken into account in the enterprise budgets for hay, silage and tillable pasture. Similarly, capital and operating costs of sprayers and combines in crop production are considered in the appropriate enterprise budgets. Fertilizer, seed, herbicides, diesel fuel, variable maintenance costs for base machinery etc. are calculated for each crop type and animal unit to be produced on the farm (Agriwise).

Modeling policy regulations

Several policy regulations are of importance when comparing the conventional system versus AMS. The following subsidy schemes are considered:

1) Direct acreage payments for grain and fallow land.
2) Environmental support payments for open tillable and natural pasture landscape and forage production.

3) Regional support payments including national direct support to milk in Northern Sweden and compensatory payments in Less favored Areas (LFA).

Direct income payments are based on the acreage of grain and fallow land. The payment level depends upon the area yield (Jordbruksverket, 1999a). Environmental support payments include payments to perennial forage crops and "open landscape". Direct income payments to forage crops are available to all farmers that grow ley and pasture on tillable land. The payment level varies across Sweden (Jordbruksverket, 1999b).

Environmental support payments to "open landscape" are conditioned on a multitude of rules relating to forage crops. Eligible crops are ley, tillable pasture and natural pasture. This support scheme is not available for farms on the plains. In Northern Sweden (support area 2a) there is also a minimum requirement in terms of the animal unit density per hectare.

Regional support payments are targeted towards production areas 2 and 3 in middle and northern parts of Sweden. The objective of these payments is to provide income support to agriculture in Less Favored Areas (Jordbruksverket, 1999c). Two categories of support payments are available. The first category ("The Compensatory Payment") is based upon the number of animal units including dairy cows, heifers etc. The payment depends upon the number of animal units. However, eligibility for the payment requires that a feed acreage restriction is not violated. According to this restriction the number of animal units is not allowed to exceed 1.4 per hectare of feed acre. Feed acres are defined as the sum of ley, tillable pasture and natural pasture. Some specific restrictions are enacted to ensure that the payments are modulated for farms with large dairy herds with more than 60 animal units.

The second category of payments is the "National Support" which is entirely targeted towards the volume of milk produced in northern Sweden, i.e. Production Area 3. This payment is a pure price support amounting to 0.71 SEK/liter milk or approximately 24%.

In the analyses no attention is devoted to the milk quota. At farm level the milk quota restriction is only effective in the event that the national quota is filled. In this farm level study it is implicitly assumed that the national quota will not be filled although AMS may increase the supply of milk.

Analyzed situations

Procedures

Analyses are conducted for six case farms in three different regions of Sweden; (Production Area 1, "Plains", Production Area 2, "Semi Plains" and Production Area 3, "Northern Sweden". Farms situated on the Semi Plains and in Northern Sweden are eligible for environmental support payments and some of, or all of, the regional support payments, depending upon the specific geographic location. Given the limited capacity of the AMS-system two farm sizes are analyzed, herd size of 60 cows for the use of one AMS and 120 cows herd size for the use of multiples of robots.

The case farms in each region are chosen to be representative for farms with the corresponding herd sizes used in the study. Utilizing data from Statistics Sweden, the resource availability in terms of tillable acreage and natural pasture is identified for dairy farms with 50 – 80 and 100-130 cows respectively. On each case farm, the economic consequences of investing in the AMS system, π_{AMS} , are evaluated in comparison to a conventional free stall milking system, π_{CONV}. Figure 3 displays a schematic overview of the situations that are analyzed for each case farm. Sensitivity analyses are conducted for every case farm to investigate the impacts of different assumptions pertaining to the effects of AMS technology upon milk yield and labor requirements. A sensitivity analysis is also conducted for the case of a "family farm situation" where the opportunity cost of labor is assumed to be zero.

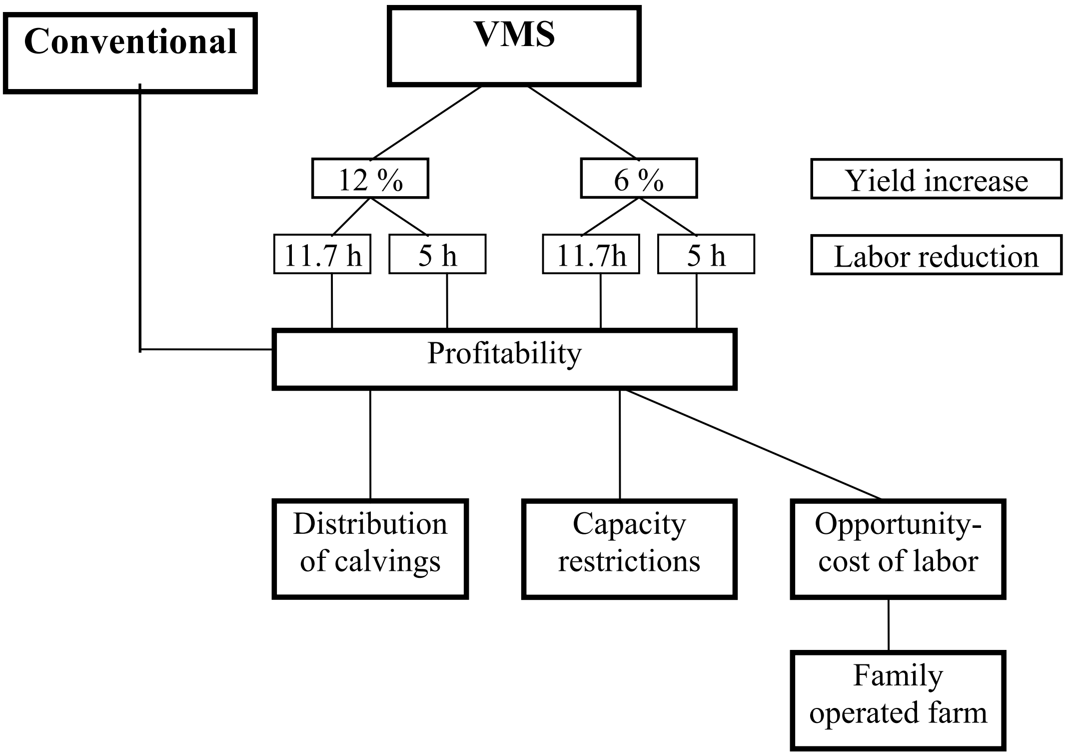

Figure 3. Schematic overview of the analyzed alternatives

Case farms

Case farm 1 and 2 are located on the Plains (Pl). Case farm 3 and 4 are located on the Semi Plains (SPl) and finally farms 5 and 6 are located in Northern Sweden (NS). Differences between the regions concern the effective milk price, seasonal variation in the milk price, natural conditions for plant production and available subsidy schemes.

Table 3. Specification of the case farms and associated restrictions

Factor	Case farm					
	1	2	3	4	5	6
Location	Pl	Pl	SPl	SPl	NS	NS
EU-subsidy area	-	-	5	5	2a	2a
Dairy cooperative	Arla/Sm	Arla/Sm	Arla	Arla	Norrmej	Norrmej
Tillable land (ha)	107	182	91	141	115	163
Natural pasture (ha)	20	45	23	35	6	25
Herd size	60	120	60	120	60	120

Sm = Skånemejerier
Norrmej = Norrmejerier

Results and discussion

Beneficiaries of AMS

The analyses clearly demonstrate that the economic impact of AMS technology on dairy farms varies greatly between the analyzed case farms. Figure 4 shows that in the base scenario the AMS system is more profitable than a traditional milking system on all case farms. Geographic location, i.e. natural growing conditions and subsidy programs, has a large effect on the benefits of AMS. In addition, economies of scale occur when the new technology is introduced. Farms that invest in multiple AMS units receive a higher return on investment than farms that invest in only one AMS unit. Figure 2 displays the impact on net farm income attributable to investing in the AMS system versus a conventional milking parlor system, i.e. π_{AMS} - π_{CONV}.

High grain yields enhances the economic value of an AMS investment in the Plains. The reason is that the AMS technology requires slightly less silage/hay per dairy cow compared to the conventional free stall system. Consequently, in the Semi Plains where the profitability of cash cops such as wheat, barley etc is lower than on the Plains, the economic impact of investing in the AMS system is somewhat lower compared to the Plains. The by far greatest economic benefits of investing in an AMS system, as compared to a conventional system, are obtained in Northern Sweden. This region is characterized by extensive subsidy programs that are directed towards ley crops thereby lowering the opportunity cost of silage/hay. In addition, a national price support on milk, amounting to approximately 0.71 SEK/liter milk, further accentuates the economic effect of an increase in milk yield attributable to the AMS technology. In the sensitivity analysis, conditional upon a 5 hour labor reduction, it is illustrated that the 120 cow case farms gains substantially more from the investment in the AMS system than farms with 60 cows. It is noticeable that when the labor reduction only amounts to 5 h, the AMS system is not economically rational for the 60 cow farms on the Plains and the Semi plains.

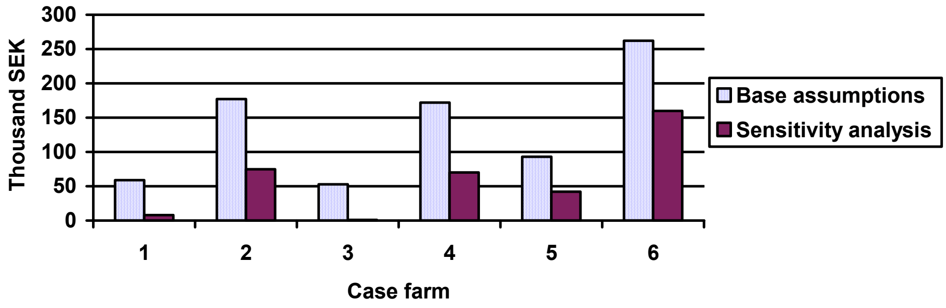

Figure 4. Economic value of AMS measured as, π_{AMS} - π_{CONV}. The base case assumes a 12% increase in milk yield and 11.7 h/year/cow labor reduction. The sensitivity analysis is based on a 12% increase in milk yield and 5 h/year/cow annual labor reduction.

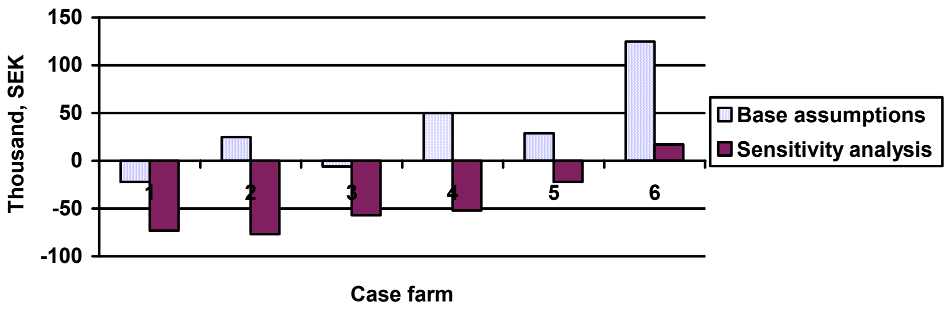

Figure 5. Economic value of AMS, π_{AMS} - π_{CONV} . The base case assumes a 6% increase in milk yield and 11.7 h/year/cow labor reduction. The sensitivity analysis is based on a 6% increase in milk yield and 5 h/year/cow annual labor reduction.

If the milk yield response to the AMS technology amounts to solely 6 percent, in combination with labor savings of 5 hours per cow and year, the results change drastically (Figure 5.) In the latter scenario the AMS technology is only economically justifiable for the 120 cow operation in Northern Sweden. In all of the other regions, the investment is simply not profitable. Even in the case where the milk yield response is at a modest 6%, but the labor reduction is substantial (11.7 h/cow/year), the investment is not profitable for the 60 cow farms on the Plains/Semi Plains. However, the AMS system remains economically viable for the 60 cow farm in Northern Sweden. Figure 6 illustrates the internal rate of return (IRR) on the marginal investment in the AMS project. The base case refers to a 12% increase in milk production and 11.7 h labor reduction. The sensitivity analysis reflects the most pessimistic scenario with a 6% milk yield response and 5 hour labor reduction. It is evident from figure 6 that in the latter case the AMS system is only economically justifiable on the 120 cow operation in Northern Sweden. Figure 6 also reveals that the IRR is highly sensitive to the assumptions regarding milk yield response and labor reduction. This effect is mainly due to the fact that the marginal investment in the AMS system, measured as additional investment per cow relative to a conventional milking system, is substantially lower for the 120 cow alternative versus 60 cows (Table 2.).

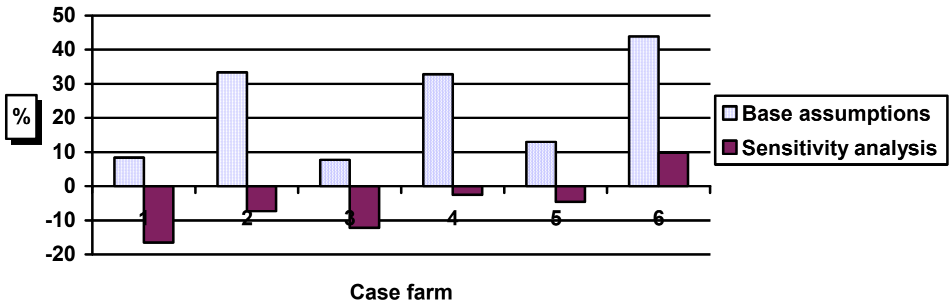

Figure 6. IRR on the marginal investment in AMS. Base assumptions refer to a 12% increase in milk yield and 11.7 h labor reduction. The sensitivity analysis assumes a 6% increase in milk yield and 5 h labor reduction.

Economic value of improved capacity of the AMS system

An AMS system is characterized by a capacity restriction that limits herd size. The marginal value of improved capacity has been analyzed for each production period as well as the whole calendar year. Typically, the capacity restriction (eq (3)) is binding for every production period for all case farms. The marginal value of improved AMS capacity reveals how much the economic surplus increases if one unit of extra capacity is supplied. This information can be used to infer how technological advances associated with the AMS unit, as well as building design that affect cow traffic in the barn, may affect the economic viability of the AMS technology.

Table 4. Marginal value of one unit of additional AMS capacity over the entire calendar year (Thousands SEK)

Assumptions	Case farm					
	1	2	3	4	5	6
12% yield response 11.7 hour/ cow/ year	10.3	10.3	11.3	11.3	20.8	20.8
6% yield response 11.7 hour/ cow/ year	8.5	8.5	9.9	9.0	19.3	18.5
12% yield response 5 hour/ cow/ year	9.3	9.3	10.2	10.1	19.8	19.8
6% yield response 5 hour/ cow/ year	7.5	7.5	8.9	8.0	18.3	16.9

Not unexpectedly the marginal value of improved capacity is the highest in Northern Sweden and the lowest on the Plains. In addition, the value of improved performance is sensitive to the assumptions regarding milk yield response and labor reduction. The marginal value of increasing the capacity of the AMS unit(s) typically amounts to 40 – 60% of the product value, measured as revenues of milk sold per cow. However, the value of extra capacity varies during the different production periods. Factors such as seasonal pricing systems, natural growing conditions, and length of grazing period do also affect the distribution over the year. Figure 7 illustrates the seasonal fluctuations in the value of additional capacity on farms 1 and 5. In the case of farm 5 the marginal value is affected by the national milk price support scheme in Northern Sweden. There is a tendency that the value of extra capacity is quite high in June-July and October- November for farm 1 due to a combination of seasonal pricing and grazing period. The opportunity cost of insufficient capacity is at its peak during period June through November in the case of farm 5 situated in Northern Sweden. This period coincides with the period with maximum milk price paid to producers.

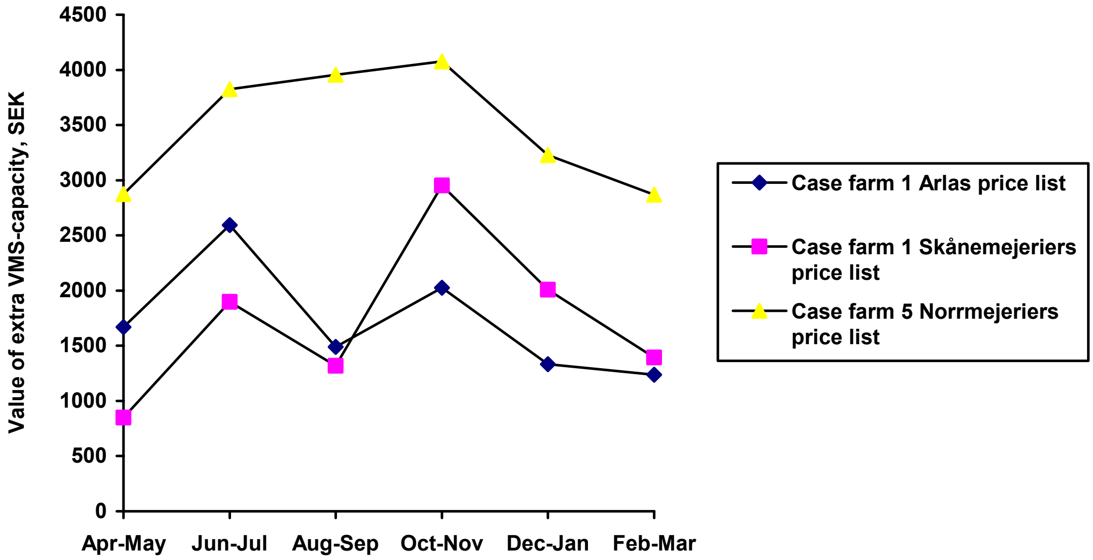

Figure 7. Marginal value of extra AMS capacity on case farm 1 and 5.

Seasonal variation in milk production

AMS systems tend to alter the optimal distribution of calvings across the seasons in comparison with a conventional free stall system. A concentration of calvings to the February – July period is the preferable strategy in the conventional free stall system (Figure 8). This result is quite robust for all case farms irrespective of whether the seasonal pricing systems for Arla or Skånemejerier are applicable. The reason for this result is that, given the parlor system, it is possible to expand the number of cows during the grazing period. In addition, milk production based on grazing tends to reduce feed costs. Concentrated calving, resulting in a high proportion of cows that calve in the same period and remain at the peak of the lactation curve, provides a bottleneck in the AMS system. In order to effectively utilize the capacity of the AMS system, the optimal calving pattern is equally distributed over the year. Accordingly, seasonal fluctuations of milk production are reduced to a minimum with AMS technology.

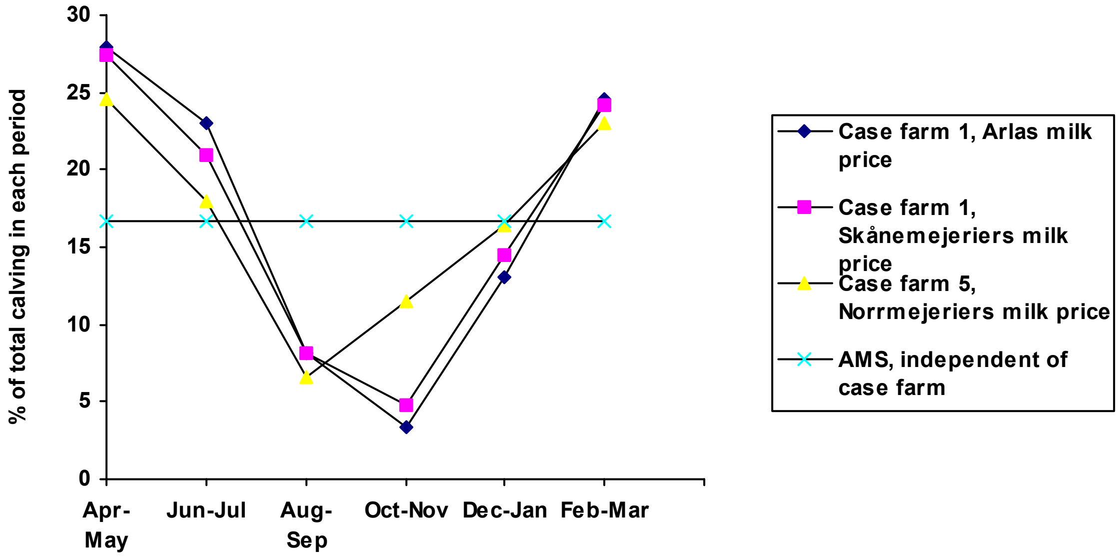

Figure 8. Optimal distribution of calvings. Case farm 1 and 5.

Family farms and opportunity cost of labor

Many dairy farms in Sweden with a herd size around 60 cows are family operated. Alternative use of family labor in revenue generating activities is not always feasible for this farm category. This means that the labor saving feature of the AMS technology is mitigated, so the main economic gain now originates from the expected increase in milk yield. As a consequence, investment in an AMS is not profitable for the case where the imputed cost of labor is zero. However, time usually has some value. Table 5 displays the threshold labor value required to make the investment in AMS technology profitable in four scenarios. As expected, the threshold value is the highest with a high milk yield response and large labor savings, especially in Northern Sweden. Table 5 also displays the amount of labor released through the introduction of an AMS system. It is obvious from table 5 that the AMS provide family operated farms the possibility to, at a reasonable opportunity cost, reallocate working hours within the farm operation or to increase leisure time. However, the threshold value increases substantially if the milk yield response to the AMS technology is low and if the labor savings remain modest. The latter result is quite apparent, especially for farm 1. In the latter case the farmer would have to be able to supply surplus farm labor to an alternative off-farm activity earning 286 SEK/hour.

Another way of interpreting the results is that for farm 5, given a 12% milk yield response and 11.7 h labor reduction, it is possible to introduce the AMS system lowering the farm family income by no more than 709x 17=12053 SEK per year.

Table 5. Threshold value of labor at various levels of milk yield response and labor savings per cow in order to make the investment in an AMS system a profitable alternative on a family operated farm with 60 cows

Assumptions	Case farm 1	Case farm 3	Case farm 5
12% yield response 11.7 hour/cow	58 SEK/h 726 hours	68 SEK/h 735 hours	17 SEK/h 709 hours
6% yield response 11.7 hour/cow	143 SEK/h 726 hours	148 SEK/h 735 hours	108 SEK/h 767 hours
12% yield response 5 hour/cow	117 SEK/h 362 hours	134 SEK/h 371 hours	30 SEK/h 400 hours
6% yield response 5 hour/cow at	286 SEK/h 362 hours	294 SEK/h 371 hours	206 SEK/h 400 hours

Concluding remarks

The results of this study rest on specific assumptions. Modeling procedures and the analyzed situations have been chosen to be representative for the specific features characterizing the Swedish policy environment. Nevertheless, the developed model is applicable for a multitude of dairy farming systems in Europe and North America given that the model is properly parameterized.

The study shows that an AMS system is more profitable than a conventional system on most of the analyzed case farms. However, this result is very sensitive to how much milk yield is increased and how much labor is saved in comparison with a conventional milking parlor system. The AMS system is more expensive and therefore some yield increase and/or labor savings are necessary to make AMS a viable alternative. The analysis shows that the larger farms benefit relatively more from using AMS. This feature of the technology may contribute to further size expansion of dairy farms.

Surprisingly, the gains from AMS technology are larger in Northern Sweden where the natural growing conditions are less favorable. This result is due to present subsidy regulations, which for a given farm size make dairy farming relatively more profitable in Northern Sweden compared to the plains in the Southern Sweden.

The limiting capacity of the AMS unit makes it economically rational to distribute the calvings evenly throughout the year. Consequently, seasonal variations in farmers' milk deliveries to dairy plants are mitigated. It is also apparent from this study that the economic value of technological improvements that increase the capacity of the AMS unit are substantial. An increase in the technological performance of the AMS system makes it even more competitive given that the milk yield response remains within the ranges quoted in the literature. Yet another interesting result is that the marginal value of improved technology is the highest in the Northern parts of Sweden, which is defined as a Less Favored Area (LFA) in the CAP policy provisions. However, the marginal value of an improvement of the AMS technology to a large degree depends upon the national price support for milk in Northern Sweden. A decoupled form of support would therefore reduce the marginal value of technological improvements even in this region.

Another implication of the AMS technology is an anticipated reduction of labor employed in the dairy industry and an increase in the use of capital. Fewer people will receive their income from the dairy sector. Consequently, the dairy industry will become even more capital intensive, thereby providing additional financial obstacles towards entry into the industry. At the same time increasing capital intensity and reducing labor use may be in contrast towards some of the intentions behind recent EU policy proposals for a prospective reformation of CAP. Reform proposals involve added attention towards rural development concerns in the LFA regions of the EU.

Several aspects have not been included in the analysis. One factor is the impact on herd health. In this study it is assumed that the AMS system, in comparison to the conventional parlor system, will experience the same level of health problems in the dairy herd (Hillerton and Winter). Hillerton and Winter actually found a lower rate of mastitis in groups of cows that were milked three or four times per day compared to groups milked twice. The economics of animal health and product quality issues associated with the introduction of AMS, as well as the actually realized production results at farm level, remain vital areas for future research within the area. Another area of empirically relevant research refers to the adjustment costs of introducing AMS. Finally, the AMS technology has the effect of lowering the marginal cost of production by 7-8%, and thereby shifting the supply curve of the industry downwards. Consequently, further research needs to consider the national as well as international policy and trade implications of the AMS technology in the event of a widespread adoption.

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