Implication of the introduction of automatic milking on dairy farms

Literature review on the determinants and implications of technology adoption

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Abstract

This paper gives a short overview of the literature on technology adoption in agriculture in general and on automatic milking in particular. First, the determinants of technology adoption are discussed in general. Next, the literature on the socio-economic determinants and implications of AM-system adoption is summarised. More specifically, the paper discusses first how economic profitability is affected by AM-system adoption. In a second part, non-economic factors related to human capital, labour and social welfare are being assessed. In a third part, animal welfare and environmental considerations are discussed. The paper concludes with some considerations related to uncertainty, timing of adoption and institutional constraints.

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Introduction

Automatic milking represents a revolutionary innovation in dairy farming. In general, an innovation can be characterised by its rate of adoption and diffusion. Adoption refers to if, when and how much a particular firm will start using an innovation. Diffusion is aggregate adoption and refers to the extent of market penetration of an innovation (Sunding and Zilberman, 2000). This paper provides a literature review on the adoption of automatic milking systems (AM-system) – or robotic milking – on dairy farms. The first section gives a short overview of the main topics in the general literature on adoption of new technologies in the agricultural sector. The second section reviews the existing literature on the introduction of AM-system on dairy farms. As comprehensive studies of the determinants and socio-economic implications of AM adoption are still absent from the scientific literature, this review is limited to evidence from experimental farms, simulation studies and case studies. Furthermore, the review turns to farmers magazines as an additional source of how present knowledge on AM-systems is being disseminated to the farming community. A final section concludes this paper.

1 Technology Adoption in the Agricultural Sector

1.1 Basic model

The adoption of a new technology can be modelled using the following simple model:

$$\max_{\delta} U\left[\delta(\pi_1 Q - K) + (1-\delta)\pi_0 Q, L(\delta)\right] \qquad \textbf{[1]}$$

where δ refers to the adoption of the new technology ($\delta = 1$) or not ($\delta = 0$), π_0 is profit per unit of output using the old technology, π_1 is profit per unit of output using the new technology, Q is total farm output, K is the investment cost of the new technology, L refers to leisure and U is a concave, continuous and twice differentiable utility function. The underlying assumptions of this simple model are that there is no uncertainty, there are no dynamic considerations, the new technology is indivisible and the investment cost of the new technology is fixed. Each of these assumptions can be relaxed. For example, a certain innovation may only be applied to part of the farm. Or, investment cost may decrease with output. However, we will only introduce uncertainty and dynamic considerations later on. The first order condition of the maximisation problem in (1) is simply:

$$(\pi_1 - \pi_0)Q + \lambda \geq K \qquad \textbf{[2]}$$

where λ is the marginal increase in leisure following innovation. This condition states that the benefits of innovation should be at least as great as its cost. Alternatively, we can write (2) as $Q \geq (K-\lambda)/(\pi_1-\pi_0)$, which is the threshold level of output below which the innovation is not profitable.

The threshold model was introduced by David (1969) to explain adoption of grain harvesters in 19th century USA. However, Olmstead and Rhode (1993) have shown that often farms much smaller than the threshold farm size derived by David have adopted the innovation, e.g., by co-operating with other farms. This demonstrates some of the limitations of the threshold model to predict adoption and assess diffusion. Farm size is, however, not the only source of heterogeneity among farmers that may explain differences in adoption. All factors affecting profitability and output may be a source of heterogeneity. For example, Akerlof (1976) has suggested that differences in human capital result in thresholds and differences in adoptions. Two empirical approaches have emerged from the threshold model:

- In the more popular approach, the dependent variable denotes whether or not an innovation is used and econometric techniques, such as probit or logit, are used to explain discrete technology choices. For example, El-Osta *et al.* (2000) examined the impact of technology adoption on production performance of a sample of dairy farms.

- In the second approach, the dependent variable denotes the duration of technology use and also uses limited variable techniques (e.g., Tobit) to explain duration.

McWilliams and Zilberman (1996) found that the two approaches provide similar answers, but duration analysis better captures the dynamics of diffusion.

Social scientists have always emphasised the role of distance and geography in technology adoption (Rogers, 1962). Geography sets two barriers to adoption: climatic variability and distance. Distance may matter as it increases travel and transport costs, and thus information costs. Such costs raise the investment cost of innovation, K, in the threshold model. Rural sociologists also first described diffusion of innovations as an S-shaped function of time, with an initial period of low adoption followed by a takeoff period with rapid market penetration. In his seminal study on the adoption of hybrid corn in Iowa, Griliches (1957) developed an economic version of the S-shaped diffusion curve and confirmed that profitability gains positively affect adoption. Feder *et al.* (1985) review a large body of empirical studies that originated in the work of Griliches.

1.2 Uncertainty

A new technology may increase the amount of risk associated with farming. Modelling uncertainty involves converting specification (1) to an expected utility model, replacing the function U into EU. Profits π_0 and π_1 are now random variables with expected value of m_0 and m_1 and variance of σ_0^2 and σ_1^2 respectively (Just and Zilberman, 1983). In theory, several strategies exist to deal with the uncertainty with respect to the performance, reliability and appropriateness of a new technology (Sunding and Zilberman, 2000):

- First, a product-backup system can be established to deal with breakdown or major malfunction. The combination of a warranty agreement and a well-functioning technical support system reduce the amount of risk. The availability and quality of mechanic shops for repair and maintenance will determine the risk farmers face and their ability to carry risk.

- Second, the appropriateness of new technology can be enhanced through extension and, where possible, trial periods. Innovations may require special skills and training that can be provided to the farmer through product information and demonstration.

- Third, money-back guarantees can be introduced allowing farmers longer periods of experimentation. In this case, the price of the technology includes some payment for the option to return it.

- Fourth, sometimes machinery is rented rather than purchased or custom services are being used for an initial trial with new technologies.

1.3 Dynamic considerations

Timing of adoption may vary across farms following the results from the threshold models discussed earlier, suggesting differences in farm size, human capital and other factors as explanatory variables. However, decision-makers consider the possibility of delaying innovation adoption to take advantage of favourable dynamic processes or to enable further learning. For example, the marginal benefits of learning-by-doing may accelerate the time of adoption, while learning-by-using will reduce the manufacturing cost of new technology assets and thus K over time. These effects can be added to the model.

However, adoption may also be delayed to wait for new information upon which adoption will be reassessed. The value added thus created is called option value (McDonald and Siegel, 1986; Dixit and Pindyck, 1994). Incorporating "real options" into the farmer's decision-making process changes the model into

$$\max_{T} \sum_{t=T}^{\infty} E_{S_t} \frac{[\pi_1(S_t) - \pi_0(S_t)]Q}{(1+r)^t} - \frac{K}{(1+r)^T} \qquad \textbf{[3]}$$

disregarding leisure and with r the discount rate, T the time of adoption and S_t a random variable affecting profits. The nature of the solution depends on the assumptions concerning the evolution of random variables S_t. S_t may be the price of output or input, but also policy (e.g. environmental regulation, production quota).

1.4 Conclusions

Which part of the economics of technology adoption in agriculture is likely to be relevant for studying the AM adoption?

Clearly, AM adoption represents the acquisition of an indivisible asset. Even in the case more than one AM-system is purchased, AM adoption is very much a 0-1 choice. The analysis of its determinants can thus be simplified to dichotomous models such as probit and logit models. In addition, the purchase of an AM-system is usually an irreversible investment, although a return to a conventional milking system cannot be excluded. As a result, duration studies are of not much use.

As far as the nature of the influencing factors is concerned, farm size will be a key factor due to the indivisibility of the AM-system. Threshold models will thus be particularly suited for studying AM adoption. Distance and geography is less likely to play an important role in a study of AM adoption in densely populated North Western Europe.

Finally, both uncertainty and dynamic considerations play a prominent role in the decision to adopt an AM-system. This is not only because of the uncertainty and future evolutions of the technology itself, but maybe even more as a result of the uncertainty surrounding the future of the whole EU dairy sector. World Trade Organisation negotiations are expected to lower institutional prices for milk; the abolition of quota is discussed in the framework of the reform of the Common Agricultural Policy (CAP); compensatory payments for price cuts are increasingly subject to environmental requirements; and last but not least environmental pressure is likely to strengthen legislation limiting the deposition of nutrients from agriculture.

In the next section, a review will be provided of the existing stock of knowledge concerning the economics of AM adoption, as reported in the scientific literature and in part of the professional literature. As comprehensive studies of the determinants and socio-economic implications of AM adoption are still absent from the literature, this review is limited to evidence from experimental farms, simulation studies and case studies. Hence, the review also turns to farmers magazines as an additional source of how present knowledge on AM-systems is being disseminated to the farming community.[1] We will organise this overview along the lines of the above discussion, i.e., starting with a lengthy discussion of the basic factors of adoption (profitability, farm size), followed by some considerations related to uncertainty and dynamics.

[1] The limitation to mainly Dutch sources has two reasons: (1) relatively difficult accessibility of the authors to sources in other countries, and (2) the fact that AM adoption and experience has been most profound in the Netherlands.

2 AM-adoption

2.1 Changes in farm management following the AM adoption

The latest innovation in dairy farming is the milking robot, which has been introduced on a commercial farm for the first time in 1992. The milking robot is developed to make the physical assistance of the farmer during the milking of each cow unnecessary. This is however only the smallest change on the farm (Kuipers and Van Scheppingen, 1992). For optimal benefit, a whole Automatic Milking System (AM-system) is built around the robot, not just as a replacement for a milking parlour, but as a management appliance. Hence, the AM-system differs from other agricultural technologies in that it not only takes over a process previously executed by men, but it implies a whole new way of managing a dairy farm. It not only changes the way the milking is carried out, but also the farmer's schedule, the feeding and the housing management.

The AM-system integrates three management functions: *milking frequency*, *individual concentrates allocation* and *cow traffic*. The use of these three functions makes it possible to implement a planned regime in the milking robot dairy and to control it. Additional important functions of the system are the monitoring of milk quality, of cow and udder health and of cow fertility. A Management Information System (MIS), integrated in the system, analyses performance data for each cow and executes management decisions through expert systems. By incorporating milking frequency, concentrates allocation and cow traffic on an individual basis into the system's management functions, the full production potential of each cow can be utilised. This can result in a good utilisation and a high efficiency of the technological facilities (Devir *et al.*, 1997). By using the data provided through the MIS for the observation of the cows, health and welfare problems may be detected earlier.

2.1.1 Farmer's tasks and schedule

When milking in the traditional way, the farmer spends a large amount of time as physical labour working with animals (Spahr and Maltz, 1997). The AM-system leads to a complete change in farmer tasks. Since there is no more (physical) contact between the robot farmer and the cow during milking, other ways of controlling and managing are necessary. On-line data collection and processing have to be done to monitor individual cows and to control their feeding and milking process (Rossing *et al.*, 1997). Therefore, a large number of sensors are incorporated in the modern AM-system (Spahr and Maltz, 1997). They measure different parameters (concentrate intake, milk temperature, colour, conductivity, etc.) that can be used for the detection of changes in health, production, reproduction and concentrate intake. In some cases even body weight can be measured. An MIS makes these data available and interpretable for the dairy farmer.

A farmer's task becomes one of management and supervision (Spahr and Maltz, 1997) because a large part of the manual labour saved must be spent on the observation of the cows, as the herd has to be observed for diseases and other problems (Kuipers and Van Scheppingen, 1992; Dijkhuizen *et al.*, 1997). This can be done very effectively if performed on the basis of the attention lists produced by the MIS (Kuipers and Van Scheppingen, 1992). The information received in this way can help the farmer to take better management decisions (Sonck, 1996).

The AM-farmer needs to understand the importance of optimal hygienic conditions in the feeding and resting area in order to keep up the milk quality (Armstrong and Daugherty, 1997). The automatic teat cleaning system does not distinguish the dirty teats. When it (frequently) happens that teats are so dirty that the standard cleaning method is not sufficient to clean them, problems with milk quality may occur. To keep the udders and teats as clean as possible, hygiene has to be followed up consequently (Landbouwleven, 2000c).

Another part of the labour is needed for the maintenance of the complicated equipment, to check the system for mechanical flaws and for proper functioning. If a system disturbance occurs, this mostly has to be solved with human help (Dijkhuizen *et al.*, 1997).

2.1.2 Feeding management

Grazing is generally considered to be of high importance for the image of agriculture as well as for cow health (cows remaining inside all year-round *may* have more problems with fertility and hoof disorders). The idea that they would have to give up grazing may even be one of the reasons for a farmer not to invest in an AM-system. However, actual practice shows that the AM-system does not exclude the possibility of grazing.

The decision for grazing has to be implemented in accordance with the AM-system capacity limitations (Devir *et al.*, 1997). The level of difficulty/easiness of combining grazing with an efficient use of the AM-system will depend on how grazing is defined. Grazing defined as 'the possibility for the cows to walk outside during some time' should be rather easy to realise on most farms. Most farmers, however, consider grazing to be 'the intake of a considerable amount of dry matter in the field'. This will be more difficult to realise, as organisational problems will have to be solved. It is difficult to tempt cows from fresh pastures and to make them come to the robot (Parsons and Mottram, 2000). It may require a lot of puzzle work and adaptations to keep the milking frequency at an acceptable level when grazing, but it is feasible (Hogenkamp, 1999c). Sonck (1995) showed that limited grazing during one long period of the day applied during summer and transition periods scores very well in terms of labour. Artmann and Bohlsen (2000) found that half days at a pasture directly next to the farm did not significantly alter either milking or visits to the milking box when controlled traffic (i.e. the cow has to pass the AM-system if it wants to go to the basic ration feeding area) and free access to the milking boxes (i.e. no selection gate before the AM-system) was applied. According to Sonck (2000), grazing has to be limited to a maximum of 8 hours to still obtain an efficient use of the capacity of the milking robot.

Offering grazing cows a high level of mixed feed in the stable can be a way to solve the problem. Salomonsson and Spörndly (2000) found that a group of cows that received roughage supplements in the stable spent less time grazing and more time indoors compared to a group without supplements. The behaviour of the first group was strongly influenced by sward height: a higher sward height caused them to graze less and to eat more indoors.

It may happen that farmers consider the practical and economic disadvantages too important to continue grazing (Roovers, 1999). Grazing narrows down the milking frequency possibilities and thus decreases the efficiency of the robot (Kuipers and Van Scheppingen, 1992; Roovers, 1998). Therefore, when adopting an AM-system, often transition will occur to limited grazing, zero grazing or summer feeding.[2]

However, the adoption of an AM-system may not be the (only) reason for limiting or giving up grazing. Also environmental issues can influence the choice for a certain feeding management, for instance when mineral surpluses are taxed (e.g., MINAS in the Netherlands).

With summer feeding or zero grazing, the capacity of the robot can be fully exploited (Kuipers and Van Scheppingen, 1992) and less time is needed for the fetching of cows compared to robotic farmers applying grazing. Indoor feeding also makes the use of pasture land easier to plan. Another advantage of summer feeding is that the cows' diet is more constant over the year, which has a positive impact on production (Kuipers and Visch, 1998). When grazing, the varying quality of the pasture may have a negative influence on the production of the high-yielding cows. The disadvantages of all-year housing are the increasing costs of forage production and feed supply (Kuipers and Van Scheppingen, 1992) and the fact that it may have a negative influence on animal health and welfare (Kuipers and Visch, 1998). With summer-feeding or zero-grazing, labour shifts away from cow fetching towards forage production and feeding (Kuipers and Van Scheppingen, 1992).

[2] Summer feeding and zero grazing are both systems where the cows do not leave the stable anymore and eat respectively preserved forage or freshly mowed grass (Sonck, 2000).

2.2 Factors affecting AM-system adoption

2.2.1 Economic factors: expected profitability and financial situation

2.2.1.1 Expected profitability

It is logical that AM-system adoption will be more likely when its expected profitability—that is, the expected difference between returns and costs—is higher. For purposes of illustration, we report the direct costs of an AM-system as described by Kowalewsky and Fübbeker (1999) in a study from the "Landwirtschaftskammer Weserems" in appendix 1, and the relative economics of AM-system adoption versus a reference using data of the Denzo-group, a group of six dairy farmers in Friesland, The Netherlands, in appendix 2.

The economic impact AM-system adoption depends on the following factors (Landbouwleven, 2000c):

- What will be the capacity of the system? The efficiency of the system (the utilisation of the AM-system and the milk yield per milking box per day) determines its overall capacity and thus the profit relative to a conventional system. A higher capacity makes the robot economically more attractive (especially on large-scale farms) and more flexible to work with (Sonck, 1996).

- Will there be an increase in milk production after the introduction of the AM-system? After making a number of assumptions, Arendzen and Van Scheppingen (2000) found that the room for investment in the AM-system enlarged by about 48% when milk yield per cow increased from 0 to 10%.

- Does the introduction fit with the purchase of a new stable, with the renovation or the replacement of the old stable?

- What is seen as a reference milking installation?

- How much labour is present on the farm? And which type (family or hired labour)?

- How does labour requirement change with the AM-system? Will there be a labour reduction and if so, how will the free time be used? A change in labour requirement has a high and linear effect on the room for investment (Arendzen and Van Scheppingen, 2000).

- What was the previous feeding system? What will be the grassland use system and the feeding system after introduction?

- Does the AM-system lead to a decrease/increase in herd health, leading to changes in the veterinary costs? In that case the relative economics of the AM-system versus the conventional milking system will change (Dijkhuizen *et al.*, 1997).

The costs of the above-mentioned factors are difficult to predict. Their contribution to the change in farm profits is determined by the specific situation on the farm and by the management capacities of the farmer. Especially the extent to which the farmer really exploits the positive effects that the AM-system can generate is important (Arendzen and Van Scheppingen, 2000). This will depend on the farmer's knowledge about and experience with the system. (More about the factor 'human capital' can be found in section 2.2.2.). To be cost-effective, cows will need to be motivated to use the AM-system as many hours as possible (Parsons and Mottram, 2000). Considering the amount of factors playing a role, it is clear that there is a considerable variation possible in the effect of an AM-system introduction on profits for similar sized farms, and that it is very difficult to draw conclusions on the optimal number of milking boxes to use from herd size alone.

Most studies about the profitability of the AM system expect that dairy farmers renovating a farm building or building a new stable are the main group for whom the decision for the introduction of the AM-system arises (Parsons and Mottram, 2000; Arendzen and Van Scheppingen, 2000; Dijkhuizen *et al.*, 1997; Kuipers and Van Scheppingen, 1992). They compare AM-adoption with the purchase of a traditional system, as they assume that the producer is at a point where the existing milking system needs replacing or requires modernisation. However, a survey among 32 German and Dutch robot users learned that only 22% of them needed a new stable at the time of the AM-system introduction (Decuyper in Landbouwleven, 2000a). In addition, these studies always apply to a very specific set of assumptions and farm characteristics, such that it is difficult to generalise their results.

According to Parsons and Mottram (2000), the robot is competitive with the conventional milking parlour for zero grazing systems, if the price of quota is low and assuming that the robot shows the same reliability as the conventional milking system. They used a simulation model to test the costs and benefits of different management regimes for the AM-system. In another study, Dijkhuizen *et al.* (1997) estimated the break-even level of AM-system adoption on a 125-dairy cow farm in the Netherlands and the USA. The break-even level, defined as the equivalent level of investment to make the AM-system as profitable as a conventional milking parlour, was found to be nearly double that of the herringbone parlour system. A sensitivity analysis showed that the break-even level was particularly sensitive to changes in wage rates.

The profitability of the automatic milking system can also be expressed in the *maximum acquisition value* (MAV), i.e. the amount of capital that may be invested in the system to achieve the same net farm result as with a traditional milking parlour. If the investment exceeds the MAV, net farm results will be smaller (Kuipers and Van Scheppingen, 1992). In that case, farmers who base adoption solely on the perception of how the new technology or equipment will increase the profitability of the dairy farm, will not invest in the robot (Armstrong and Daugherty, 1997). Farmers looking for labour savings, more freedom, increased cow welfare etc. will only invest if they expect the lower profitability to be compensated by a desired fulfilment of their expectations.

The MAV highly depends on the desired alternative for automatic milking. Capital which would normally be invested in renovation or replacement of a traditional milking parlour can be invested in an AM-system (Kuipers and Van Scheppingen, 1992). In practice, it can be expected that farmers considering buying an AM-system would also prefer a high degree of automation for the layout of a traditional milking parlour. The difference in investment with an AM-system will therefore be smaller. For farmers who would decide in favour of a cheaper and lower-tech alternative milking parlour, the step towards an AM-system is bigger.

In an interview with Nieuwenhuis (1999), Buiks asserted there is hardly a difference in cost per kg milk with the AM-system compared to the traditional milking system. According to Buiks, "the higher fixed costs through the purchase of the AM-system, are compensated by the lower rate of variable costs, which is due to the higher production and the better udder health exceeding the increasing power and maintenance costs". Some caution is needed concerning this assertion. In most cases, combining the increase in gross margin due to higher milk yields and the decrease in gross margin due to changing over to another grazing or indoor feeding system will result in a lower gross margin (Kuipers and van Scheppingen, 1992). The increase in milk yield varies considerable amongst farms (cf. section 2.2.1.3) and the discussion whether cows milked by a robot have a better udder health is still open.

2.2.1.2 Farm size

The AM-system will have the highest efficiency on farms with herd sizes that fit to the robot (Kuipers and Van Scheppingen, 1992) or, conversely, on farms where the farmer is willing, and able, to adjust the herd size to the AM-system. It is obvious that the milk yield per cow and the desired milking frequency are important factors in determining the number of cows that can be milked with an AM-system. The system's capacity (if expressed as number of cows per milking unit) also depends on whether the equipment is used efficiently (Devir *et al.*, 1997). In practice the milking frequency on commercial farms is 2.6 to 2.7 milkings per cow per day on average. The number of cows milked per hour mostly depends on the steady voluntary cow traffic throughout the day (Spahr and Maltz, 1997). According to the manufacturers, the capacity of a

1-box robot is 60 cows when the average daily milking frequency is assumed to be 2.8 to 3.0 milkings per cow. With a second box, they assert it to be 90 or 120 cows, depending on the system (differences are possible in the method of teat cleaning, system cleaning, teat cup attachment etc.) (Schoonhoven, 2000). Kingmans (1999) described how the available quotum influences the exploitation of the robot capacity as follows: “Having a quotum above approximately 450,000 litres, a 1-box system will be overloaded, while a second box will be under-utilised and thus used inefficiently. Farmers having a quotum that can be milked efficiently by a 1-box, but who want to expand the milking activity in the coming years, will also be confronted with a capacity problem. Only for a large growth, a second box becomes economically interesting”. It should be noted that in practice, there is a large variation in number of cows and litres of milk that are milked with a similar AM-system.[3] Milk yield per cow and number of milkings per day are important determinants of the system’s capacity. Furthermore, farmers can gain in capacity by selection of faster milking cows and by a more efficient use of the system when becoming more experienced.

For bigger herds (150 cows or more), a larger number of logistic and practical problems have to be solved to optimise cow traffic in the stable and feeding when adopting an AM-system (Hoefman, 1998a). Armstrong and Daugherty (1997) studied the possibility for adopting an AM-system on very large dairy farms, with hundreds of cows and with a lot of employees. Such farm sizes are not very common in Europe: they are mostly found in the USA and make use of cheap immigrant labour forces. On these farms, the advantage of higher milk yields by using the AM-system disappears, because they already reach milking frequencies of three or four times a day with a traditional milking parlour. Approximately one third of the herd on such large US farms are first lactation cows. Since every new cow needs special attention to adapt her to the system, the authors believe this will seriously reduce time savings expected with the AM-system.

In the past, new technology in milking systems has more readily been adapted by dairy farms when it could be used in existing facilities (Armstrong and Daugherty, 1997). The present types of AM-systems are only suitable for cows that are not tied, consequently with cubicle loose housing only. For farms which do not have such a stable yet (the minority of farms in North-western Europe), the AM-system will be less attractive because they will have to invest more (Kuipers and Van Scheppingen, 1992).

[3] Although in the beginning it was believed that for a one-box system the maximum level of milk per year would be 500,000 litres, there are now units producing over 800,000 litres per year (Aart van ‘t Land, personal communication).

2.2.1.3 Increase in milk yield per cow

A dairy farmer may aim for a higher milk production per cow. The reason for this can be either to keep down the variable costs of the herd in the long term by milking the quota with a smaller number of cows, or to enlarge herd size and production per cow to profit from increasing scale. According to Bart Sonck (personal communication), most farmers do not have the intention to cut down their herd size because they see this as a step back. They usually think in terms of growth and enlargement. For example, a survey showed that only 20% of the 32 interviewed robot milkers considered the higher production rates as an argument (Decuyper in Landbouwleven, 2000a).

The production increase with the AM-system is reached through increased milking frequency and by combining individual milking and feeding strategies (Kuipers and Van Scheppingen, 1992; Devir *et al.*, 1997). Kuipers and Van Scheppingen (1992) assumed a 10 to 15 % higher milk yield per cow to be possible. These values have been reached on experimental farms, but on commercial farms production increases are generally lower (with 5% as the estimated average) (Bart Sonck, personal communication). Moreover, the production increase has a fair amount of variance (Dijkhuizen *et al.*, 1997) and the advantage of a higher yield by increase of the milking frequency is gradually diminishing due to genetic progress (Landbouwleven, 2000a).

If a milk production increase occurs due to the AM-system use, quota can be milked with fewer cows. In that case, the European robotic milker has to choose between the purchase of additional milk quota or a reduction of herd size. If all the new milk produced requires a lease of quota to cover it, an AM-system becomes much more unprofitable (Cooper and Parsons, 1999). An objection can be raised against the previous statement since the purchase of quota is no necessity when buying a robot; this is dependent on the farmer's choice. Besides, also farmers not having an AM-system can choose to milk three times daily to increase milk yield and to buy quota. According to Dijkhuizen *et al.* (1997) reducing herd size is economically the most interesting option when milk quota are at a high price level (e.g., 2.04 Euro in the Netherlands).

As a consequence of the higher milking frequency or an enhanced freezing point caused by a slightly larger percentage of water in the milk or a combination of these two factors, a reduction in fat content (approximately 0.15%) may occur when milking automatically. There may also be an effect on protein content, but less apparent (a decline of 0.05% on average) (Dijkhuizen *et al.*, 1997). Lower fat and protein levels imply a slight decrease in the milk price for the farmer. Some farms have problems with milk quality after adoption, which can be due to an increase in the somatic cell count, a raised free fatty acid content or an increase in total bacterial count. It should however be stressed that the management of the farmer plays a determinant role in keeping up the milk quality level, in case of traditional as well as for automatic milking.

2.2.1.4 Financial situation

The presence of financial reserves affects the readiness and willingness to invest. There is a strong variation between the availability of financial resources on dairy farms (Kuipers and Van Scheppingen, 1992). For those with a favourable financial situation, the possibility of introducing an AM-system is higher. If a farm is already carrying a large debt load and additional debt may put the business financially at risk, then the AM-system with its high capital requirement may be less attractive (Dijkhuizen *et al.*, 1997). Moreover, the high investment may cause a high mental load on the farmer (and his family) (Sonck, 1996). The expected decrease of the milk price as a result of the WTO-agreements will put additional pressure on the profitability of dairy farming. As a consequence, the willingness to invest in new (expensive) technologies will probably decrease. Kuipers and Van Scheppingen (1992) contend that the evolution towards free trade can thus be a major impediment to technical developments like the AM-system.

2.2.2 Non-economic factors: human capital, labour and social welfare

Traditional farmers are generally risk-averse. They may seek security in using the same traditional methods their parents used and in avoiding borrowing money, even for investments. However, farmers may be interested in the milking robot, because of the attraction of something new and revolutionary. The AM-system may become a new kind of status symbol in dairy farming or it may be considered in the future as a necessity for a farmer's quality of life and pleasure at work. The conflict between looking for security and trying something new will influence the decision for or against adoption of the AM-system.
In an interview with Hoefman (1998a), Van Scheppingen distinguished between three groups of dairy farmers:

1) farmers who choose for the robot despite an expected decrease in farm profits, because of their high appreciation of the expected labour reduction or the expected increase in flexibility, in milk production, in cow health, etc.;

2) farmers who only choose for the robot if they expect farm profitability to stay equal or to increase;

farmers who do not want to work with an AM-system because they prefer a strict daily planning and want to control the milking process themselves, or for other reasons.
Obviously, the introduction of an AM-system is not a good choice for every farmer. Its success largely depends on the specific farm situation (Kingmans, 1999). Particularly in the early days,

farmers returned to the traditional way of milking after disappointing experiences with the AM-system. The reasons they gave were: disappointing labour reductions, problems with milk quality, the fact that one was not able to relax carrying a beeper that can give an alarm at any time of the day, disorders cows suffered from, high maintenance and electricity costs, high prices for quota reducing the possibility to increase capacity or difficulties to deal with the financial aspect (Hoefman, 1998b). The unfulfilled expectations or undesired implications may have been due to the 'child diseases' of the system or to the fact that information on the consequences of adoption was still scarce.

2.2.2.1 Labour

A reason why a dairy farmer may be interested in robotic milking is the expectation of a reduction in labour. The change in labour time after adoption is however difficult to estimate. It is very different from farm to farm and largely dependent on the chosen management functions, namely the system of cow traffic and the feeding system (from limited grazing to summer feeding) (Devir *et al.*, 1997). Also the reliability of the technology, the level of use of the technology, the position of the AM-system in the stable, the herd size and the portion of the herd that can not be milked automatically play a role. For example, Artmann and Bohlsen (2000) found that the labour time required on four farms with the AM-system ranged from 127% to 54% in comparison to conventional milking in herringbone parlours. Although this study was done on a very limited sample, it may give an indication of the largely varying results of labour time on AM-farms. Roovers (1999) stated that especially on one-person farms, the labour time gained for work outdoors or for other farm activities will be limited.

According to Artmann and Bohlsen (2000), an AM-system with a fully-functioning facility and with consideration of a higher level of animal monitoring can create the possibility to save about two-thirds of the time needed in conventional milking practices. According to a study by Sonck (1995), the AM-system with human-controlled cow traffic applied during the whole year and with an average milking frequency of three times a day results in physical labour savings for milking of maximum 38% (or 470 hours/year). With computer-controlled cow traffic and cows kept indoor the whole year, a maximum reduction of 66% (or 821.3 hours/year) is reached. These percentages exclude time needed for repair or unexpected trouble shootings. Other studies mention potential labour savings of 300 up to 950 hours a year or as much as 2.6 hours a day for a herd size of 125 (Landbouwleven, 2000b; Dijkhuizen *et al.*, 1997).

It is generally accepted that the physical workload will decrease after adoption of an AM-system. Milking is classified in the category of light to moderately heavy labour (Belt and Zegers, 1984). Health complaints a milker may have with back, neck and shoulders will be reduced by the introduction of an AM-system (Hildebrand, 1989; Rossing *et al.*, 1997). The amount of repetitive monotonous tasks strongly diminishes. This can be the main reason for an older farmer with physical problems to choose for the AM-system, namely to be able to continue farming in an easier way.

2.2.2.2 Schedule

The farmer's vision on labour organisation is an important factor in the decision in favour or against an AM-system. Some farmers prefer to work in peak moments, whilst others prefer a lighter, but more continuous load (Bart Sonck, personal communication). When milking in the traditional way, a farmer is tied to fixed milking hours 7 days a week. Moreover, the traditional milking hours are considered to be socially unfavourable. With an AM-system, the farmer is relieved from the fixed daily milking times. The farmer has more freedom of time planning during the day, more flexibility and the opportunity to have a life-style more in line with that of people working in other sectors. This may make an important difference for the farmer's social life.

On the other hand, a robot user must be available 24 hours a day to solve possible disturbances. Unpredictable interventions can be necessary when the system breaks down or when abnormal cow behaviour blocks the activities of the AM-system. These interventions will disturb the daily labour planning and even social activities of the farmer and his family. This may cause stress to the farmer, especially when work of a high priority has to be interrupted, and to the family life. The reliability of the AM-system will play an important role in this. The fact that one can get alarmed at any time of the day can be experienced as worse than the usual milking process (Sonck, 1995; Sonck, 1996). Some farmers only feel comfortable working with a strict planning: to milk in the morning and in the evening and to execute the other work in between the milking sessions (Hoefman, 1998a).

2.2.2.3 Nature of the work and work climate

In case of automatic milking, the contact with the cows is expected to be less intensive (Sonck, 1995). This idea can be one of the reasons not to buy a robot. Some farmers consider the contact with their animals of major importance for their pleasure at work and see it as the loss of a major element in their stockmanship to give away the milking task to a robot.

With an AM-system, however, a good contact with and control of the cows remains very important for the health of the herd and consequently for a good technical result (Roovers, 1999). Only good care makes it possible to realise high productions in a justified way. A survey among Belgian robot milkers showed that most farmers did not feel to have less contact with their cows. On the contrary, thanks to the robot they had more time to observe their cows and to walk between their cows (MML, 2000). Furthermore, the robot farmer can do his routine checking at a moment of the day he chooses himself without having to milk at the same time.

Physical environmental elements such as light, noise and climate are rather unfavourable in a conventional milking parlour. As the AM-farmer will spend less time in this unfavourable environment, the system can contribute to the health of the farmer (Sonck, 1996). In addition, milking conventionally is not without any risks according to statistics on accidents. Positive effects can be expected with the AM-system as there will be less direct contact with animals: the incidence of labour unfitness caused by milking activities will be rare.

2.2.2.4 Human capital

The AM-farmer must be capable of analysing and interpreting the data delivered by the MIS. This requires a different kind of knowledge and insight. The farmer must develop an appropriate sense for technology and animal observation (Artmann and Bohlsen, 2000). The time needed to learn and enhance the new management skills before and while starting-up the AM-system should not be underestimated (Dijkhuizen *et al.*, 1997). Not every dairy farmer is interested in such a way of managing his farm. Some farmers doubt the reliability of an MIS to monitor the milking of the cows and to detect problem cows; some just prefer a more physical task above a more supervisory one (Dijkhuizen *et al.*, 1997; Cooper and Parsons, 1999). One may expect that particularly young, dynamic farmers with a higher education level would be less reserved against the new technology. However, according to Bart Sonck (personal communication) the farmer’s interest in computer technology and in the relation cow-technology is far more important than the education level and is independent of the farmer’s age.

2.2.2.5 Strategic plan of the farm

The AM-system must be compatible with a farmer’s strategic objectives (Kuipers and Van Scheppingen, 1992). Before deciding in favour or against adopting an AM-system, a farmer should first outline a strategic plan (motivations and goals) for the farm. The plan must take into account the farmer’s needs and wishes and the available facilities, possibilities and constraints (Hogenkamp, 2000a; Devir *et al.*, 1997). Further, it must have a solid financial base (Wassink, 2001).

The robot is more likely to be a justified investment for large farms with a clear growth strategy in combination with limited availability of labour (Kingmans, 1999). Many of these farms are already more intensive and feed more in the stable, making the step towards robotic milking smaller. They try to save costs by use of technology, by full automation of the daily milking and the feeding routine (Kuipers and Visch, 1998; Devir *et al.*, 1997). Their aim is to keep income up by increasing scale and by increasing labour productivity and production efficiency (Devir *et* *al.*, 1997, Kuipers and Visch, 1998). For these farms, the price of quota can play a key role in the decision for an AM-system.

A more extensive type of farming attracts some farmers. They do not like the idea of limited or zero grazing and increasing the milk production per cow is not one of their main goals. Some of these farmers have the desire to integrate their dairy farm into a system of countryside stewardship or nature development. The robot may not really fit in their way of farming. Organic farming is expected to be more nature minded but is also very labour demanding. This way of farming does not necessary conflict with a high rate of automation. In a way, the AM-system can facilitate the switch to organic farming because it makes the standard for cattle occupation easier to realise (Boerderij, 2000a). Moreover, the robot can help to solve the (potential) labour problem. A large number of organic farmers (especially in Denmark) are already using an AM-system, whilst other organic farmers think that intensification and high technological farming is not compatible with the principles of organic farming (Boerderij, 2000b).

Dijkhuizen *et al.* (1997) distinguished two types of farms for which the adoption of an AM-system has a strong appeal: relatively large family farms and farms using hired labour:

- The most common type in Europe is the *family farm*, where usually only one person is available to do the milking. On these farms, existing labour force may be overloaded due to the increased difficulty to find family or casual labour. In most cases, family farms want to grow with own labour force. They prefer the robot above having to rely on external labour for milking their cows (Hoefman, 1998a). The introduction of an AM-system on one-person farms can create the possibility for enlarging dairy herd, for the introduction or expansion of additional activities or businesses into other sectors or for becoming a part-time farmer. The last option is to have more spare time (more personal freedom), the value of which is difficult to express in money but is highly appreciated by the farmers (Nieuwenhuis *et al*., 1999).

- In countries with a *high level of labour costs*, the profitability of the AM-system will be high for large dairy farms with external labour, that are willing and able to discharge redundant labour force or can deploy this labour in a different way. The profitability of the AM-system on these farms is particularly sensitive to changes in wage rates (Dijkhuizen *et al.*, 1997). Possibilities are restricted since most EU dairy farms are family farms without externally hired labour. An exception is Germany, but Kuipers and Van Scheppingen (1992) made the assumption that large German farms would not buy a robot because the labour was not educated for the required technical knowledge. Employees on these farms are usually specialised in their job assignment i.e. milking, feeding and animal health, which limits the possibilities to use their labour elsewhere on the farm (Armstrong and Daugherty, 1997). It is however not proven that this fact restrains German farmers from adopting an AM-system. In countries where large farms have trouble acquiring labour for milking (e.g. Germany, Denmark) robotic milking can offer the solution (Roovers, 1998).

2.2.3 Animal welfare and environmental considerations

2.2.3.1 Cow health and welfare

The milk yield per cow has almost doubled in the last 30 years. The long intervals between traditional milking sessions might not be optimal for the welfare of high yielding cows (Rossing *et al*., 1997). The higher milking frequencies possible with the AM-system can fit the natural pattern better when a comparison is made with the frequency of suckling in beef herds (4 to 6 times per 24 hours) (Day *et al.*, 1987). More frequent milking causes a lower tension on the udder offering the cow more comfort to lie down and leading to increased lying times (Sonck, 1996; Nieuwenhuis, 1999). Shorter milking intervals reduce discomfort due to udder pressure after several hours of milk accumulation (Kuipers and Van Scheppingen, 1992), decreases stress on the udder ligaments by reducing the maximum accumulated milk present in the cow's udder and decreases the time for growth of mastitis organisms (Spahr and Maltz, 1997). However, the increased total milking time can cause extra stress on the teats and an increased number of teat end erosions and eruptions (Rossing *et al.*, 1997; Sonck, 1996). The fact that one teat cup is used for the entire herd can lead to a quicker spread of bacteria if one cow has mastitis or high somatic cell count (Yvonne Van der Vorst, personal comment).

Through the integration of sensors on the AM-system with on-line data acquisition, monitoring of cows is done more consistently, faster and continuously in comparison with human observation. Deviations and diseases may be detected earlier resulting in improved animal health and welfare (Sonck, 1996). However, farmers may have problems with the interpretation of the measurements made by the sensors and the detection of clinical mastitis by the system may not be sufficient yet (Karin Knappstein, personal comment).

It is obvious that until now, there is no agreement on whether the AM-system is better for cow health or not. Again, the possible difference after adoption of AM will not be the result of the new milking system only, but also of the changes in feeding system and in cow management.

Increasing milk production by a higher milking frequency has an effect on energy demands and on its complex relation with body reserves balance (Devir *et al.*, 1997). The feeding has to be adapted accordingly, not only to attain full benefit of multiple milking but also to maintain cow's health (Spahr and Maltz, 1997). Farmer's attention must also go to the creation of the right conditions for the herd, such that the cows are regularly milked and the system can function optimally. Especially with year-round housing, when cows stay inside during the summer months, ventilation in the stable is very important.

Farmers report less stress among the cows, less hierarchical battles within the herd and more peace in the stable as a result of AM (Nieuwenhuis, 1999). The reason for this is that cows with low dominance values adapt their visits to the AM-system and the feeding gate to the cows with higher dominance by visiting both parts of the cowshed more at quiet times (Rossing *et al.*, 1997).

2.2.3.2 Replacement rate

Not all cows are able to adapt to the AM-system. The udder shape of some cows may not be appropriate. Others may be very nervous or have hoof problems such that they do not come voluntarily to the AM-system or stand very uneasily during the application process, causing complications during the attachment of the teat cups (Artmann and Bohlsen, 2000). Armstrong and Daugherty (1997) found that in general, farmers are willing to replace 5% of the herd to be able to utilise new labour saving technology, but they resist replacement rates of 10% or more. The largest number (78 to 84%) of cows that have difficulties to adapt to the robot and have to be fetched are in their third lactation or more (Landbouwleven, 2000a). Old cows with ill shaped, deep udders and wide teats may need to be culled for a lesser degree of defect than is the case with conventional milking systems (Spahr and Maltz, 1997).

2.2.3.3 Selection

With the AM-system, the importance of the uniformity of the herd increases. The farmer will adapt his breeding program towards cows that are optimally suited to be milked by the robot. Detailed research and practical experiences will reveal which characteristics automation requires as regards the exterior traits of animals. The uniformity of the udder shape is one important characteristic for a smoother functioning of the robot (Kuipers and Van Scheppingen, 1992).

Some cows may have problems with lipolysis occurring, when milked three or four times a day. Lipolysis (or a higher free fatty acid contents in the milk) negatively influences milk taste, cheese and butter making (Sonck, 1996). Kuipers and Van Scheppingen (1992) regarded it as a task for research to find out which animals can be milked three or four times a day without problems with lipolysis occurring.

Due to a transition to limited or zero grazing, cows can suffer more from hoof disorders that lead to low visiting rates (Devir *et al.*, 1999). Possibly, breeding might help here in that animals are selected for their resistance to such problems (Kuipers and Van Scheppingen, 1992). Also the milking velocity can be influenced by breeding and selection (Landbouwleven 2000b).

2.2.3.4 Energy consumption and environment

In recent years, increased attention is given by politicians and by the public opinion in Western Europe to the impact of dairy farming on the environment and to the energy use and surpluses on dairy farms. In this respect, it is of interest how the AM-system will influence the energy balances of a farm.

Concentrates are the major energy consumers in dairy farming, followed by fertilisers. With the AM-system, the concentrate requirement per individual cow is higher. The higher milk yields per cow and the fact that concentrates are used as bait for the cows to come to the robot are the main reasons. The needed amount of concentrates per quantity of milk is expected to stay equal. Substantial reduction of energy consumption will be possible when growing concentrate crops on the dairy farm, but the price situation makes concentrate growing not attractive in the Netherlands (Kuipers and Van Scheppingen, 1999).

Due to the higher milk yields, fewer cows can be held on an AM-farm to reach the milk quota and less animal waste may be produced (Sonck, 1996). Forage requirement of the herd will be smaller if the productive capacity (forage, labour and accommodation) is not used for additional young stock or beef cattle. The lowered requirement will result in a forage surplus. This is the reason for Wassink (2001) to mention the ample availability of forage on farms as a possible contribution to the non-introduction of the AM-system on a farm. This seems to be a far-fetched factor, since the surplus can easily be limited by applying less nitrogen fertiliser to the land (with a lower energy consumption as a result) and the surplus can be sold. Limiting the addition of nitrogen will influence positively the energy balance of a farm.

Together with the introduction of the AM-system on a farm, often transition occurs to limited grazing, zero-grazing or summer feeding for reasons of efficiency. When year-round housing, nitrate leaching can be reduced as well as the occurrence of urine patches in the pasture. Ammonia emission can be lowered when year-round housing is applied in adapted housing facilities, but this implements additional investments. The result is a higher efficiency of mineral inputs.

Artmann and Bohlsen (2000) report an increase in the total water and energy use after AM-adoption. Also in Landbouwleven (2000c) the electricity use with the AM-system is said to be higher than with traditional milking. However, the water and energy use is very dependent on the type of system (this is true for automatic as well as for traditional systems). No studies are available yet comparing energy and water costs per litre of milk between the AM-system and the traditional system.

2.2.4 Risk considerations

The AM-system requires a substantial capital investment in machinery, management program-system and housing equipment. The introduction of an AM-system generally also requires an adaptation of facilities as well as modifications of the feeding and resting area. In most cases this creates more costs than originally thought, what makes that extra investments are necessary. Examples are: adaptations in the stable, an extra milk refrigerator tank, possibly the displacement of water- and power supply, fence work for the control of cow traffic, etc. (Nieuwenhuis *et al*., 1999).

The reliability of the AM-system will strongly determine the socio-economic effects as well as the effects on labour aspects (Sonck, 1996).

2.2.5 Dynamic considerations

The high investment cost of the robot is an adverse factor towards adoption rate (Kuipers and van Scheppingen, 1992; Armstrong and Daugherty, 1997). According to Parsons and Mottram (2000), who assessed herd management aspects of robotic milking on UK dairy farms, an AM-system will have to sell at a lower price to be competitive with current conventional milking parlours. A reduction of the price of the robot over time, as occurs for most technological innovations (if they become more popular) will favour the introduction. However, the manufacturers do not expect a decrease in investment rate since the robots will become better and more complete (Bart Sonck, personal communication). To make it possible to spread the investment over more litres, the manufacturers are searching for systems that can handle more animals per milk box (Landbouwleven, 2000c).

2.2.6 Institutional constraints

Intensive dairy farming gets in conflict with governmental regulations on ammonia emissions, overproduction of manure, fertilising limits and water protection (Sonck, 1996). Institutional constraints such as government regulations will influence the scope and speed of adoption of an AM-system (Dijkhuizen *et al.*, 1997; Cooper and Parsons, 1999) can play a role. For example:

- When taxes on mineral surpluses (e.g. MINAS in the Netherlands) gain more impact in the future, more farmers may consider leaving their cows in the stable (Hogenkamp, 1999b). All-year housing is better for utilisation of minerals but also for the occupation of the robot.

- A governmental regulation obliging farmers to lead the cows to pasture can slow down adoption speed. The effect in the European countries would probably be small because most (future) robot milkers want to combine the AM-system with grazing, despite the lower efficiency. For example, in Belgium, the quality chain control for milk (IKM) prescribes a grazing period (Eddy Leloup, personal communication), while in Sweden, grazing is compulsory by law.
- The European regulations on milk hygiene prescribe that the milk must be visually inspected before entering the tank. This is impossible with an AM-system, leading to restrictions for AM-users. For example in Denmark, AM-farmers have to participate in a self-monitoring programme. In Germany, a catalogue of measurements with special demands for AM-farms is applied in some federal states. The uncertainty with regard to the legal situation may therefore be an important factor that limits the number of new adopters in Germany (Yvonne Van der Vorst, personal comment; Karin Knappstein, personal comment).
- In Denmark, the threshold level for somatic cell count is higher for robot milkers than for conventional milkers: 300,000 cells/ml and 400,000 cells/ml respectively.
- In Belgium, quotum constraints hinder the growth of the dairy farms. Quota are managed and divided by a special fund. The amount of quota that can be acquired per year is particularly small. Belgian farms cannot reach scale advantages and for this reason, investments in the dairy sector are postponed. Only small, necessary innovations are executed. When the quota market would be liberated enabling the farmers to expand in an appropriate way, the adoption rate of the robot is expected to speed up (Bart Sonck, personal communication).

3 Conclusions

This paper has given a short overview of the literature on technology adoption in agriculture in general and on automatic milking in particular. Recently, the general literature not only studies the impact of farm size, human capital, financial and institutional constraints on technology adoption, but it more and more tries to take into consideration the role of uncertainty and timing. Many farmers delay adoption to wait for more information (less uncertainty) concerning the technology itself as well as the institutional environment.

The literature on the socio-economic determinants and implications of AM-system adoption is found to be limited to simulations and case studies. Hence, it is impossible to generalise their results, such that this review cannot present final conclusions. Moreover, in addition to a trade-off between the direct financial costs and benefits of AM-system adoption, the AM-system also brings about non-financial costs and benefits which are difficult to measure, such as increased flexibility of the farmer's working day, impact on animal welfare, etc., but which are important elements in a farmer's choice.

Bibliography

Akerlof, G., 1976, The economics of caste and of the rate and other woeful tales, *Quarterly Journal of Economics* 90: 591-617.

Arendzen, I. and van Scheppingen, A.T.J., 2000, Economical sensitivity of four main parameters defining the room for investment of automatic milking systems on dairy farms, in: Hogeveen, H. and Meijering, A. (eds.), *Robotic Milking, Proceedings of the international symposium held in Lelystad, The Netherlands, 17-19 August 2000*, Wageningen Pers, Wageningen, p.201-211.

Armstrong, D.V. and Daugherty, L.S., 1997, Milking robots in large dairy farms, *Computers and Electronics in Agriculture* 17: 123-128.

Artmann, R. and Bohlsen, E., 2000, Results from the implementation of automatic milking system (AMS) – Multi-box facilities, in: Hogeveen H. and Meijering A. (eds.), *Robotic Milking, Proceedings of the international symposium held in Lelystad, The Netherlands, 17-19 August 2000*, Wageningen Pers, Wageningen, p.221-231.

Boerderij 2000a, Melkrobot past prima in bio-landbouw. Interview met Willem Muller, bedrijfsleider proefbedrijf, *Boerderij* 85(15): 24.

Boerderij 2000b, Melkrobot past niet in de biologische gedachte. Interview met melkveehouder Pieter Boons, *Boerderij* 85(18): 21.

Cooper, K. and Parsons, D.J., 1999, An economic analysis of automatic milking using a simulation model, *Journal of Agricultural Engineering Research* 73: 311-321.

David, P.A., 1969, *A contribution to the theory of diffusion*, Stanford Center for Research in Economic Growth, Memorandum no. 71.

Day, M.L., Imaka, K., Clutter, A.C., Wolfe, P.L., Zalesky, D.D., Nielsen, M.K. and Kinder, J.E., 1987, Suckling behaviour of calves with dams varying in milk production, *Journal of Animal Science* 65: 1207-1212.

Devir, S., Ketelaar-de Lauwere, C.C. and Noordhuizen, J.P.T.M., 1999, The milking robot dairy farm management: operational performance characteristics and consequences, *Transactions of the ASAE (American Society of Agricultural Engineers)* 42(1): 201-213.

Devir, S., Maltz, E. and Metz, J.H.M., 1997, Strategic management planning and implementation at the milking robot dairy farm, *Computers and Electronics in Agriculture* 17: 95-110.

Dijkhuizen, A.A., Huirne, R.B.M., Harsh, S.B. and Gardner, R.W., 1997, Economics of Robot Application, *Computers and Electronics in Agriculture* 14: 111-121.

Dixit, A. and Pindyck, R., 1994, *Investment Under Uncertainty*, Princeton University Press, Princeton.

El-Osta, H. S. and Mitchell, J. M., 2000, Technology adoption and its impact on production performance of dairy operations, *Review of Agricultural Economics* 22(2): 477-498.

Feder, G., Richard, E. J. and Zilberman, D., 1985, Adoption of agricultural innovation in developing countries: a survey, *Economic Development and Cultural Change* 33(2): 255-298.

Griliches, Z., 1957, Hybrid corn: an exploration in the economics of technological change, *Econometrica* 25(4): 501-522.

Hoefman, R., 1998a. Keuze voor robot grondig overwegen, *Boerderij* 83(17): 86-87.

Hoefman, R., 1998b, Klanten gezocht die bij de robot passen, *Boerderij/Veehouderij* 84(21): 18-19.

Hogenkamp, W., 1999b, Melkrobot samen met weidegang blijft puzzelen, *Boerderij* 84(43): 22-23.

Hogenkamp, W., 1999a, Bewijs verzamelen dat de robot toekomst heeft, *Boerderij/Veehouderij* 84(4): 8-9.

Hogenkamp, W., 1999c, Betere gezondheid, maar meer werk, *Boerderij/Veehouderij* 84(20): 22-23.

Hogenkamp, W., 2000a, Melkrobot geaccepteerd als volwassen melksysteem, *Boerderij/Veehouderij* 85(10): 26-27.

Hogenkamp, W., 2000b, Melkrobot is de kleinste wijziging in bedrijfsvoering, *Boerderij/Veehouderij* 85(12): 14-15.

Just, R.E. and Zilberman, D., 1983, Stochastic structure, farm size, and technology adoption in developing agriculture, *Oxford Economic Papers* 35(2): 307-328.

Keuper, J., 1999, Melkrobot wordt sneller en soepeler, *Boerderij/Veehouderij* 84(12): 14-15.

Kingmans, R., 1999, Melkrobot is niet voor iedereen weggelegd, *Boerderij/Veehouderij* 84(8): 8-9.

Kowalewsky, H.H. and Fübbeker, A., 1999, *Ermittlung der Melkleistung, der Kosten und des Arbeitszeitbedarfs bei automatischen Melksystemen*, Landwirtschafts-kammer Weser-Erms, Referat Landtechnik.

Kuipers, A. and van Scheppingen, A.T.J., 1992, *Dairy farming and automatic milking. Present knowledge and prospects*. Proefstation voor de Rundveehouderij, Schapenhouderij en Paardenhouderij (PR), Lelystad. Rapport nr. 141.

Kuipers, A. and Visch, J., 1998, Acht ton melk per man dankzij high-tech, *Boerderij/Veehouderij* 83(7): 36-37.

Landbouwleven, 2000a: Robot melksystemen geëvalueerd. Bespreking van het eindwerk van Bavo Decuyper, 7 juli 2000, p. 15.

Landbouwleven 2000b: Keuze en inpassing van een melkrobot, 1 september 2000, p. 19-20.

Landbouwleven 2000c: Melkrobot en melkkwaliteit, 8 september 2000, p. 14.

McDonald, R. and Siegel, D., 1986, The value of waiting to invest, *Quarterly Journal of Economics* 101: 707-728.

McWilliams, B. and Zilberman, D., 1996, Time of technology adoption and learning by doing, *Economics of Innovation and New Technology* 4: 139-154.

MML, 2000. Sociale kenmerken van de robotmelker en de sociale gevolgen van het robotmelken. Ministerie van Middenstand en Landbouw (België-, Onderzoek en Ontwikkeling, Ontwikkeling Dierlijke Productie. Not published.

Nieuwenhuis, M., 1999, Alles gericht op groei, welzijn en efficiëntie, *Boerderij* 84(50): 8-9.

Nieuwenhuis, M. and Hogenkamp, W., 1999, Winst robot kwestie van lange adem, *Boerderij/Veehouderij* 84(15): 8-9.

Nieuwenhuis, M., 2000, Hogere voerkosten drukken saldo melkrobotboeren, *Boerderij/Veehouderij* 85(3): 8-9.

Olmstead, A. L. and Rhode, P., 1993, Induced innovation in American agriculture: A reconsideration, *Journal of Political Economy* 101 (1): 100-118.

Parsons, D.J. and Mottram, T.T.F., 2000, An assessment of herd management aspects of robotic milking on UK dairy farms, in: Hogeveen, H. and Meijering, A. (eds.), *Robotic Milking, Proceedings of the international symposium held in Lelystad, The Netherlands, 17-19 August 2000*, Wageningen Pers, Wageningen, p.212-220.

Rogers, E., 1962, *Diffusion of Innovations*, Free Press of Glencoe, New York.

Roovers, M., 1998, Melkrobots winnen overal terrein, *Boerderij/Veehouderij* 83(4): 36-37.

Roovers, M., 1999, Grootste gevaar melkrobot is industrialisering. Interview met Peter Vingerling, *Boerderij/Veehouderij* 84(8): 10-11.

Rossing, W., Hogewerf, P.H., Ipema, A.H., Ketelaar-De Lauwere, C.C. and De Koning, C.J.A.M, 1997, Robotic milking in dairy farming, *Netherlands Journal of Agricultural Sciences* 45: 15-31.

Salomonsson, M. and Spörndly, E., 2000, Cow behaviour at pasture with or without supplementary roughage in automatic milking systems, in: Hogeveen, H. and Meijering, A. (eds.), *Robotic Milking, Proceedings of the international symposium held in Lelystad, The Netherlands, 17-19 August 2000*, Wageningen Pers, Wageningen, p.192-193.

Schoonhoven, C., 2000, Robot verovert de markt, *Boerderij/Veehouderij* 85 (17): 15-19.

Sonck, B.R., 1995, Labour research on automatic milking with a human-controlled cow traffic, *Netherlands Journal of Agricultural Science* 43: 261-285.

Sonck, B.R., 1996, *Labour organisation on robotic milking dairy farms*, Ph.D. Dissertation Wageningen Agricultural University.

Sonck B.R., 1999, Robotisatie of automatisering in (melk)veehouderij, *Landbouwleven, 24 december*, p. 34-36.

Sonck, B.R., 2000, Robot spaart hoe dan ook handenvol werk, november 2000, *Melkveebedrijf* 0: 26-29.

Spahr, S.L. and Maltz, E., 1997, Herd management for robot milking, *Computers and Electronics in Agriculture* 17: 53-62.

Sunding, D. and Zilberman, D., 2000, The agricultural innovation process: research and technology adoption in a changing agricultural sector, forthcoming in the *Handbook of Agricultural Economics.*

Thurow, A. P., Bogges, W.G. and Moss, C.B., 1997, An *ex ante* approach to modelling investment in new technology, in: Parker, D. and Tsur, Y. (eds.), *Decentralization and Coordination of Water Resource Management*, Kluwer Academic Publishers.

Wassink, H., Keus melksysteem hangt af van ontwikkeling bedrijf, *Boerderij/Veehouderij* 86(4): 12-13.

APPENDIX 1

EXAMPLE OF THE CALCULATION OF THE DIRECT COSTS OF AN AUTOMATIC MILKING SYSTEM

A study on automatic milking was done by Kowalewsky and Fübbeker (Landwirtschaftskammer Weser-Ems, Referat Landtechnik) within the framework of the project "Ermittlung der Melkleistung, der Kosten und des Arbeitszeitbedarfs bei automatischen Melksystemen". The purpose of this study was to obtain an idea about the actual prises and the costs of the AM-system and about the changes in labour conditions on farms milking with the system. Data were obtained by questioning commercial farmers who adopted an AM-system and checked and completed by interviews with manufacturers and by systemic measurements on experimental farms. In the survey, data from 35 farms were used. Five of them were experimental farms, the other 30 were commercial farms. Twenty-three of the examined farms were located in Germany, whilst the others were Dutch farms. The installation of the AM-system on the reviewed farms was between the beginning of 1995 and the end of 1998. The data were collected in 1999. Here, we only give an overview of the direct costs associated with the purchase of an AM-system. Costs or benefits from changes in feeding management, labour time, housing, etc. are not included.

Fixed costs

In table 1 and 2 the AM-system is being depreciated over a period of 8 years using the linear depreciation rule. The amount depreciated each year is simply the price of the AM-system divided by 8. Rent is calculated using a fixed discount rate of 8%. Table 3 carries out these calculations for a discount rate of 4% and a depreciation period of 12 years.

Table 1 Fixed costs

	Price (Euro)	Asset depreciation rate	Fixed costs		
			Depreciation Euro/year	Rent Euro/year	Sum Euro/year
One-box system					
- 1 milk box	143,162	8	17,895	5,726	23,622
- 2 milk box	230,081	8	28,760	9,203	37,963
- 3 milk box	317,001	8	39,625	12,680	52,305
Multi-box system					
- 1 milk box	158,500	8	19,813	6,340	26,153
- 2 milk box	184,065	8	23,008	7,363	30,371
- 3 milk box	209,630	8	26,204	8,385	34,588
By selection gate (One box)	1,278	8	160	51	211
By selection gate (Multi box)	4,397	8	176	176	725

Table 2 Fixed costs

	Technology	Selection gate	Fixed costs		
	Euro/year	Euro/year	Building Euro/year	Sum Euro/year	Per year Euro/cow
One box system					
- 1 milk box	23,622	211	1,688	25,521	387
- 2 milk box	37,963	421	3,377	41,761	316
- 3 milk box	52,305	632	5,065	58,001	293
Multi-box system					
- 1 milk box	26,153	726	3,025	29,903	336
- 2 milk box	30,371	726	3,801	34,897	303
- 3 milk box	34,589	726	4,391	39,706	288

Table 3 Fixed costs with variable interest rates

	Fixed costs		
	Sum Euro/year	Per cow /year	Per litre Milk
One milk box			
T=8 years, r=8%	25,521	386	5.2
T=8 years, r=4%	22,302	338	4.5
T=12 years, r=4%	15,809	239	3.2
Three milk boxes			
T=8 years, r=8%	58,002	293	3.9
T=8 years, r=4%	50,598	256	3.4
T=12 years, r=4%	35,804	181	2.4

T=depreciation period, r=interest rate

Variable costs

Variable costs include costs for maintenance and repairs, water and electricity, detergents, disinfectants, filters and the heating of the milking room.

Maintenance and repair are an important part of the variable costs (see table 4). Making a maintenance contract with the robot manufacturer generally alleviates these costs. The costs for a maintenance contract in this study fluctuated between 3,426 Euro for one milking box up to 9,663 Euro for three one-box systems on the same farm. Maintenance contracts for multi-box systems cost generally less than the ones for the same number of single boxes. For example, maintenance costs for the multi-box system with three boxes and for three one-box systems are respectively 5,113 and 9,663 Euro. Comparing contracts of different companies is very difficult because the contents of these contracts are not always the same. Besides, it is also necessary to take other repairs into consideration, not included in the maintenance contract. The level of these repairs is 2 to 2.5 % of the purchase price. The costs for maintenance and repair aggregate up to 6,289 Euro for one milking box and 16,003 Euro for three one-box systems. Prices of maintenance contracts for multi-box systems are fluctuating between 4,090 and 5,624 Euro.

When calculations are made per cow, differences between the different systems and the dependence on the number of milking boxes decline. Maintenance and repair costs range from 79 to 95 Euro per cow.

Table 4 Costs for maintenance and repair

	Maintenance	Repair		Maintenance and repair	
	Euro/year	% from the price	Euro/year	Total per year *	Euro/year Euro/cow
One-box system					
- 1 milk box	3,426	2	2,863	6,289	95
- 2 milk box	6,545	2	4,602	11,146	84
- 3 milk box	9,663	2	6,340	16,003	81
Multi-box					
system	4,090	2.5	3,963	8,053	91
- 2 milk box	5,113	2.5	4,602	9,715	84
- 3 milk box	5,624	2.5	5,241	10,865	79
- 4 milk box					

*Herd with a milking frequency of 2.7 per cow and per year.

An overview of the *water and electricity costs* is given in table 5, that provides results from two research farms, as farmers could not give exact information about this cost. The amount of water, 146 m³ per year, used in one milking box in the one-box system is comparable with a conventional milking system. The water is mainly used for the cleaning of the teat cups and the milk pipeline. Only a small part is used for cleaning of the building. Looking at the cost per year in table 5, the multi-box system is more profitable in its use of water. This advantage disappears when the water use is counted per cow and not per milking box. After purification it is necessary to remove the cleaning water. This brings about an additional cost. The cleaning water is added to the manure. This implicates that the cesspit must be larger to store the water. The cost of a cesspit is about 41 Euro per m³ and the period of utilisation is estimated to be 25 years. Furthermore, it is assumed that the cesspit is full twice a year. The cost for the storage is then 1.6 Euro per m³. In addition, there is also a payment to empty the cesspit. This implies an additional cost of about 2.1 Euro per m³. Together, the cost for dumping the water as manure totals 3.7 Euro per m³. Hence, the waste disposal turned out to be three times more expensive than the costs for the use of water.

Calculating the electricity costs is considerably easier. In a one-box system, the use of electricity is 60 kWh per day and per box. In a multi-box system, the use of electricity per box is slightly less. For example, it is 80 kWh per day for two milking boxes. The price for electricity is 0.15 Euro per kWh. The estimated prices for the electricity are then between 3,359 Euro and 10,077 Euro. It is clear that the costs for electricity are higher than these for water.

Summing up, electricity and water costs in this example are between 49 and 62 Euro per cow and per year.

Table 5 Water and electricity costs

	Water			Electricity		Water and electricity	
	Use	Cost	Cost for the manure	Use	Cost	Total	Per year*
	m³/year	Euro/year	Euro/year	KWh/year	Euro/year	Euro/year	Euro/cow
One box system							
- 1 milk box	146	187	537	21,900	3,359	4,083	62
- 2 milk box	292	373	1,075	43,800	6,718	8,166	62
- 3 milk box	438	560	1,612	65,700	10,077	12,250	62
Multi-box system							
- 2 milk box	175	224	644	29,200	4,479	5,347	60
- 3 milk box	183	234	673	34,675	5,319	6,226	54
- 4 milk box	190	243	699	38,325	5,878	6,821	49

*Herd with a milking frequency of 2.7 per cow and per year

Water : 1.28 Euro/m³

Cost from manure: storage 41 Euro/m³ (depreciating for 25 years and with a rent equal to 8 % of half of the purchase price =3.3 Euro/m³/year) 2x = cost for the storage 1.7 Euro/m³ plus 2.1 Euro/m³ to empty the cesspit makes it 3.68 Euro

Electricity: One box system ca. 60 kWh/day per box; multi-box systems: 2 boxes 80 kWh/day; 3 boxes 95 kWh/day; 4 boxes 105 kWh/day; price for electricity 0.15 Euro/kWh

There are high hygienic requirements to get a high milk quality. Therefore, there is first of all the intensive cleaning of the teat cups and the milk pipeline with water. This intensive cleaning requires also the use of acid and basic cleaning equipment. The cost for this cleaning equipment is given in table 6. First, these data are based on the experience of farmers. Second, they are based on the registration of this cleaning equipment by the manufacturer during maintenance and repair of the milking box. Depending on the number of milking boxes the cost for the cleaning equipment fluctuates between 344 and 1,031 Euro. Just like before, the differences caused by the milking system used and by the number of milking boxes are small when looking at the costs per cow. The costs per cow fluctuate then between 5.2 and 6.7 Euro per cow and per year. Furthermore, it is obvious that the money paid for the cleaning equipment has an inferior role. Costs for disinfecting and dipping fluctuate between 5 and 10.2 Euro. It is remarkable that these products are not used on all farms.

Table 6 Costs for cleaning equipment with milking robots

	Cleaning equipment				Cost for the cleaning equipment	
	Acid		Alkaline			
	Use L /year	Cost Euro/year	Use L /year	Cost Euro/year	Together Euro/year	Per year* Euro/cow
One-box system						
- 1 milk box	55	98	160	245	344	5.2
- 2 milk box	110	196	320	491	687	5.2
- 3 milk box	165	295	480	736	1031	5.2
Multi-box system	90	161	270	414	575	6.9
- 2 milk box	108	193	324	497	690	6.2
- 3 milk box	117	210	351	538	748	5.6
- 4 milk box						

*Herd with a milking frequency of 2.7 per cow and per year
Cleaning equipment: acid ca. 1.79 Euro/litre, alkaline

The aim of using a filter is to prevent entering undesirable substances in the milking tank. Therefore it is necessary to change the filter three times a day. However, this also means an additional cost. Changing one filter costs 0.26 Euro. Hence the total cost for changing the filters is 280 Euro a year for a one-box system as well as for the multi-box system. In the one-box system, each milking box has a separate filter while there is only one common filter in the multi-box system. Hence, an additional milking box in a one-box system, leads to an additional filter cost. In practice, however, there are usually only two filter changes a day, which is the absolute minimum. To underspend this minimum implies a greater danger of germ multiplication. An overview of these filter costs are given in table 7.

Finally, there are also costs for heating the milking room in winter. In this way it is possible to prevent freezing in the milking box and thus assuring the milking box keeps working in winter. The best and cheapest solution is to work with liquefied petroleum gas (LPG) in combination with a simple heating system. With minimum temperatures from –10°C in the milking room, an average heating of 9.28 Watt per m² is necessary. Looking at the heating capacity of LPG and its price (0.21 Euro per litre), there is a heating cost of 129 Euro per year for a one box system with one milking box. Because of the greater room with more milking boxes, there is also a greater heating cost.

The cost for heating and changing filters are of subsidiary importance, looking at the other variable costs, shown in table 8. This table shows also the higher variable costs with an increasing amount of milking boxes. When considering the total of all variable costs per cow, the multi-box system is cheaper from the point that three one box systems would be needed. Remarkable is the importance of the costs for repair and maintenance, about half of the variable costs. The study showed that the variable costs determined on average one third of the total cost of an AM-system.

Table 7 Costs for changing filter and heating milking room

	Filter[1]		Heating milking room[2]		Other variable costs	
	Use (Number/year)	Cost (Euro/year)	Use (l/year)	Cost (Euro/year)	Total (Euro/year)	Per year* (Euro/cow)
One box system						
- 1 milk box	1,095	280	600	129	409	6,2
- 2 milk box	2,190	560	1,200	258	818	6,2
- 3 milk box	3,285	841	1,800	387	1.227	6,2
Multi-box system						
- 2 milk box	1,095	280	1,540	331	611	7,3
- 3 milk box	1,095	280	2,060	442	723	6,5
- 4 milk box	1,095	280	2,570	552	832	6,3

*Herd with a milking frequency of 2.7 per cow and per year.
[1]: Filter = changed 3 times a day
[2]: Heating milking room: there is about 9.28 Watt/m² necessary when there are minimum temperature off –10°C in the milking room. The cost existing with LPG totals 9.2 Euro/m²/year (price for LPG is 0.21 Euro/l), the rent for heating is included.

Table 8 Overview of all the variable costs

	Variable costs				Sum variable costs	
	Repair, Maintenance	Water, Electricity	Cleaning eq., disinfection	Other	Total	Per year
	Euro/year	Euro/year	Euro/year	Euro/year	Euro/year	Euro/cow
One-box system						
- 1 milk box	6,288	4,083	733	409	11,514	174
- 2 milk box	11,146	8,166	1,466	818	21,597	164
- 3 milk box	16,003	12,250	2,200	1,227	31,681	160
Multi-box						
system	8,053	5,347	1,077	611	15,088	169
- 2 milk box	9,714	6,226	1,336	723	17,998	157
- 3 milk box	10,865	6,821	1,528	832	20,045	145
- 4 milk box						

Herd with a milking frequency of 2.7 per cow and per year.

APPENDIX 2

A CASE STUDY - THE DENZO GROUP

The study group "Denzo" consists of six dairy farmers in Friesland (the Netherlands), who started with an AM-system between May 1998 and November 1998 and who were the first to make their financial results public. The farms are large and intensive with an average quotum of 720,207 litres and an intensity of 17,472 kg milk per ha, that achieved good results with the traditional milking system (Hogenkamp, 2000b).

The group reported adaptation problems for the farmer as well as for the cows in the start-up phase. The guidance by the manufacturers in the beginning was very important (Nieuwenhuis and Hogenkamp, 1999).

Transition year (Nieuwenhuis and Hogenkamp, 1999)

The farm profits of the Denzo-group decreased in the transition year compared to the year before introduction. Despite the large investments, however, they achieved better results than a reference group, consisting of 42 farms with a similar size and intensity (Nieuwenhuis, 2000).

On the revenue side, there was a slight decrease in milk price which was partly due to an overall decrease in the price paid by the dairy factory and partly to lower fat and protein percentages due to milking cows more frequently. Also the revenues out of returns and growth per 100 kg fat and protein corrected milk (FPCM) slightly lowered, in which the replacement of culled cows played a determinant role. Compensating for this was the higher milk production and the higher 'other yields'.

Concerning the changes for the variable costs, a slight decrease in feed costs was noticed because of the negative forage costs. With the AM-system it is possible to milk the quota with lesser cows. This implied a reduction of forage needed to feed the herd and had two consequences for the Denzo farmers: the use of fertilisers could be reduced and an excess of forage could be sold. The latter resulted in negative forage costs.

Especially the higher fixed and attributed costs determined the profit decrease: The attributed costs increase was mainly due to the higher costs for land and buildings, due to the adaptation of the existing buildings. Furthermore, agricultural contractor costs increased because the feeding management on the farms was changed. Cows were spending more time inside the stable and as a result more manure had to be strewed and more mowing was needed. Also energy costs increased. The combination of all this determined the profit decrease. Fixed costs showed the highest increase mostly due to the rent on and the deprecation of the AM-system and the investments for adaptation of the infrastructure. For the Denzo group, the deprecation in the first year was set at 12% of the purchase price of the robot, in later years this will decrease to 6%, but then maintenance costs are expected to increase.

The conclusion of the study group after one year was that the investment would only be an advantage in the longer term. They expected labour productivity and milk production to increase in time.

The first half-year after the transition year (Nieuwenhuis, 2000)

During the first half year after the transition year, production increased with 10% for the Denzo group in comparison to the reference group. A shift from grass to maize occurred in the same period. The influences of these changes on farm economics are listed here. Also other factors causing changes in farm economics relative to the transition year or to the reference group are described.

First, higher feed costs pushed down the gross margin of the Denzo-group. To realise a substantial production increase per cow, cows were given remarkably more concentrates. The reason for this, according to the Denzo-farmers, was that they were still trying to achieve the best feeding system. Because they did not find the right balance yet, the forage was not utilised at an optimal level and the production had to be kept up with extra portions of concentrates. Moreover, two Denzo-members were planning to turn to summer-feeding, which required additional feed costs since they had to build up an extra stock of forage.

Further, revenues decreased slightly more for the Denzo group in comparison to the reference group. Reasons for this were the lower fat and protein percentages resulting in a lower milk price and the decrease in returns and growths since the Denzo group received a lower price for sold cows and newly born calves.

Finally, a profit decrease occurred in comparison to the transition year, for the Denzo group as well as for the reference group. The most important reason for this was the low milk price in this period.

The lower calculated labour cost per 100 kg of FPCM is one of the bigger advantages for the Denzo group. The robot increased the productivity per person: more milk and more cows could be handled per person. As a consequence, the Denzo farmers were able to increase the herd to the limits of the robot without needing additional labour. The Denzo farmers stressed that for a good functioning of the AM-system, management is very important, putting cow health first.

Table 1 Farm economic data from the May-May bookkeeping of 1997/'98 and 1998/'99 and 1999/2000 of the study group "Denzo" and of the May-May bookkeeping of 1998/'99 of the reference group (in Euro per 100 kilo FPCM; farm profits in Euro)

	Denzo			Reference group
	1997/'98	**1998/'99**	**1999/2000**	**1998/'99**
Milk price	33.79	33.60	32.02	33.50
Returns and growth	2.79	2.29	2.01	3.05
Other revenues	1.94	2.55	2.30	1.47
Total revenues	38.52	38.56	36.32	38.02
Concentrates and conc. replacements	4.76	4.81	5.27	4.20
Forage	0.28	-0.29	0.42	0.64
Other feed costs	0.29	0.34	0.30	0.48
Total feed costs	5.33	4.86	5.99	5.32
Cattle costs[4]	1.81	1.72	1.74	1.96
Fertilisers	1.13	0.83	0.52	0.96
Other attributed costs	0.10	0.22	0.17	0.17
Total attributed costs	3.04	2.77	2.42	3.09
Non attributed costs[5]	7.51	8.78	8.69	6.83
Lease costs	0.60	0.59	0.76	1.35
Total rent	7.99	8.32	8.01	7.35
Total depreciation	3.33	5.57	5.87	3.58
Total fixed costs	11.31	14.48	14.64	12.27
Calculated labour	5.57	5.26	4.74	7.02
Paid labour	1.61	1.15	0.83	0.73
Total labour costs	7.17	6.42		
Profits	4.16	1.26		
Farms profits	35,942.55	12,354.16		

Data from Nieuwenhuis and Hogenkamp, 1999 and provided by the study group "Denzo".

[4] Cattle costs contain veterinary costs, insemination costs and others.
[5] Overhead costs contain costs for contract work, machinery, land and building, energy costs and other