WORKING PAPER 2013:7

Karin Bergman

Ewa Rabinowicz

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AgriFood
economics centre

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Karin Bergman* and Ewa Rabinowicz†

August 6, 2013

Abstract

This study uses survey data on Swedish milk producers, comprising adopters and non-adopters of an automatic milking system (AMS), to comprehensively investigate various aspects of the adoption decision. The results show that farmers report non-profit-related reasons as the most important for the decision to adopt an AMS, whereas profit-related reasons are the most important for the decision not to adopt the AMS. Despite problems with profitability, over 90 per cent of the AMS farmers would recommend the AMS to other milk producers. A probit estimation of the probability of investing in an AMS finds positive effects of AMS adoption in the social network, positive beliefs of future profitability and existence of a successor, and negative effects of age, experience, education, share of tenured land and regular use of advisors.

JEL Classification: O33, Q12, Q16

Keywords: Technology adoption, automatic milking, social network

* Corresponding author, AgriFood Economics Centre, P.O. Box 730, SE-220 07 Lund, Sweden. Tel: +46 (0)46 222 07 82. E-mail: Karin.bergman@slu.se

† AgriFood Economics Centre, P.O. Box 730, SE-220 07 Lund, Sweden

1 Introduction

Since the seminal paper by Griliches (1957) on the adoption of hybrid corn, a large number of studies has analysed technology adoption in agriculture. The interest in this question is based on the importance of new technology for increasing efficiency in production, and hence for economic growth. The empirical literature on technology adoption in agriculture has focused on identifying factors that explain heterogeneity among farmers, which affects the profitability of the innovation and therefore results in different adoption decisions. Feder et al. (1985) reviewed this literature and showed that most studies used factors such as farm size, education, experience and risk perception to explain this heterogeneity. More recently, the behaviour of the people in a farmer's social network has been put forward as an important determinant of the adoption decision (Borgatti et al. 2009, Valente 1996).

In this study we analyse the adoption of the automatic milking system (AMS) in Sweden. It is an example of a relatively new technology that aims at increasing profitability for the farmer at the same time as it changes the labour tasks. Less time is spent milking, but instead other work tasks are added, for example handling alarms, controlling and maintaining the AMS (Gustafsson 2009). The development of the AMS was originally driven by rising labour costs in Europe in the 1970s (de Koning and Rodenburg 2004), but a survey of 107 AMS farmers in Europe (Mathijs 2004) shows that 67 per cent declared social reasons, like spending more time on other activities, having more flexibility, improving social life and improving health, as the most important reasons for adopting the AMS. Hence, the adoption of this technology seems to be driven mainly by utility maximization and not profit maximization.

Using a new data set collected from a survey of Swedish milk producers, comprising adopters and non-adopters of AMS, this study contributes to the literature by performing a comprehensive investigation of various aspects of the adoption decision. It presents a descriptive analysis of the factors that farmers regard as important determinants of adopting or *not* adopting the AMS, and the kind of information that farmers rely on for the adoption decision. Further, the study uses regression analysis to ascertain how the probability of investing in an AMS is affected by farm and farmer characteristics, including the farmers' social network. The survey has enabled us to ask the farmers to state their own network instead of just assuming that it just consists of the neighbours, which earlier studies do.

We have asked both adopters and non-adopters of an AMS for the reasons that were important for their decision to adopt or reject the AMS. We find that the most important reason for installing an AMS is to improve the work environment, whereas the most important reason for not installing an AMS is that the investment cost is too large. The study also finds that 92 per cent of the AMS farmers would recommend the installation of an AMS to other farmers, despite indications of low profitability, and that the behaviour and advice of other farmers are important for the individual farmer's decision to adopt or not. Furthermore, the results from a probit regression show that the probability of investing in an AMS is positively affected by investment support, beliefs in profitability and adoption of the AMS in the farmer's social network. Negative associations are found for age, experience, education, share of tenured land and regular use of advisors.

The outline for the rest of the paper is as follows. Section 2 describes the automatic milking system and the literature on AMS adoption, section 3 develops the theoretical framework, section 4 contains the empirical analysis and section 5 concludes the paper.

2 Automatic milking systems (AMS)

The first AMS was installed in the Netherlands in 1992 and came to Sweden in 1998. In 2009 there were about 8000 farms worldwide using AMS (de Koning 2010) and 28 per cent of the Swedish cows were milked in an AMS at the end of 2011 (Landin and Gyllenswärd 2012). In an AMS the cows voluntarily (motivated by the supply of concentrate) enter the milking box (de Koning and Rodenburg 2004). The system identifies the cow electronically, cleans the udder, milks the cow and analyses the milk in order to detect any abnormalities. There are both advantages and disadvantages with this technology and Rotz et al. (2003) summarize some of these. One advantage is the opportunity to reduce the need for hired labour and to give the farmer more time for family and recreational activities. Another advantage is the increased milk production due to more frequent milking. The disadvantages include the large investment cost and the risk of a decrease in milk quality. It is often found that the milk quality decreases after the introduction of an AMS, but there are also findings of no differences and even improved milk quality (Andersson 2012, Berglund et al. 2002, Klungel et al. 2000, Rasmussen et al. 2002, Salovuo et al. 2005). Svennersten-Sjaunja and Pettersson (2008) highlight the fact that the AMS is not only a new technology for milking but also an entirely new management system in which the farmer has to consider milking as well as aspects such as cow traffic, feeding, cow behaviour, grazing and milk quality. AMS usage seems to be most efficient on farms with 60-260 cows (Gustavsson 2010), but there are examples of AMS farms with both much fewer and much more cows.

Labour accounts for a large part of the costs in milk production because milking takes about 25 to 35 per cent of the annual labour demand (de Koning 2010). As mentioned before, the development of the AMS was originally driven by rising labour costs (de Koning and Rodenburg 2004) and now the literature reports labour savings of 10 to 30 per cent, when comparing with conventional milking systems, and two milkings per day and similar herd sizes (de Koning 2010, de Koning and Rodenburg 2004, Gustavsson 2010, Mathijs 2004). The reason why the labour savings are not greater is because there are now other, but less physical, work tasks to perform. These tasks include controlling the output from the AMS, fetching cows that have gone too long since they last were in the milking box, teaching new cows to use the AMS and cleaning the AMS. One major difference for the farmer who installs an AMS is that even if the milking process in a conventional system is very time consuming and ties the farmer to the milking process at specific times, an automatic milking system means the farmer has to be on call 24 hours a day in order to handle possible alarms from the system (de Koning 2010, Gustavsson 2010).

The few studies analysing the adoption of the AMS are of a more descriptive nature and point at factors that influence the adoption decision (e.g. Hyde et al. 2007, Mathijs 2004, Meskens et al. 2001), or estimate the effect of individual and farm characteristics on the adoption decision (e.g. Heikkilä et al. 2012, Sauer and Zilberman 2012). The descriptive studies find that the adoption decision is influenced by profit-related aspects such as the expectation of increased profitability due to increased milk production, decreased labour costs and decreased veterinary costs, as well as non-profit-related aspects such as less physical work tasks, more flexible work time, increased social life and increased well-being for the cows. Both the regression-based studies use panel data on adopters and non-adopters. Sauer and Zilberman (2012) estimate a sequential model where the farmer first chooses whether to increase the number of cows or not, and if he/she chooses to increase, then there is the choice of whether to adopt or not. They use data on 241 farms in Denmark and find that the decision to implement an AMS is positively affected by the size of the milk production, private consumption, veterinary costs per cow, the share of hired labour in total labour, the farmer's experience in milk production, received subsidies, earlier experience in organic farming, the number of AMS farms in the village and the share of farmers who have adopted an AMS in the region. They also find that the decision is negatively affected by off-farm income, and that the more experienced farmer is less sensitive to variations in profit and therefore more likely to implement the AMS. Heikkilä et al. (2012) use data on 608 Finnish farms and note that the farms that already have a high level of mechanization and therefore a low demand for labour are more likely to implement an AMS. They also find a positive effect of investment aid on the adoption decision. Furthermore, they find that farms with an AMS have higher productivity growth than farms with conventional milking systems.

3 Theoretical framework

It is common to model a farmer's behaviour as utility maximizing and not profit maximizing (see e.g. Adesina and Baidu-Forson 1995, Misra et al. 1993, Rahm and Huffman 1984). Lin et al. (1974) test this hypothesis and find that farmers indeed seem to follow a utility maximizing behaviour. Following Rahm and Huffman (1984), the different technologies to choose from are denoted by j, where j is equal to 1 for the old technology and 2 for the new technology. The utility function for the ith farmer can be denoted $U(R_{ji},A_{ji})$ where the utility level with technology j depends on a vector of profits with this technology, R_{ji}, and on a vector of attributes associated with this technology, A_{ji}. With AMS as the new technology these attributes include more time for leisure or other work, fewer physically heavy work tasks, fewer potential problems finding competent personnel or managing the personnel etc. The vector of profits with AMS includes the cost of adoption, a lower cost for labour for a given output and possible income from other production at the farm or from another job for which the farmer now has more time. The utility function is unobservable, but the expected utility derived from the jth technology is assumed to have a linear relationship with a vector of observed farm and farmer-specific characteristics, X_i, and a random disturbance term with a zero mean:

$$E\left[U_{ji}\right] = X_i\alpha_j + e_{ji}, \qquad j = 1,2. \tag{1}$$

Farmers are assumed to choose the technology that gives them the largest expected utility. The ith firm adopts the new technology if the expected utility with the new technology, $E[U_{2i}]$, exceeds the expected utility with the old technology, $E[U_{1i}]$. We denote this difference y_i^* and let the variable y index the adoption decision with $y_i = 1$ if a farmer adopts the new technology and zero otherwise. The probability that y_i equals 1 can be expressed as a function of farm and farmer characteristics:

$$\begin{aligned} \Pr(y_i = 1) &= \Pr(y_i^* > 0) \\ &= \Pr(E[U_{1i}] < E[U_{2i}]) \\ &= Pr(X_i\alpha_1 + e_{1i} < X_i\alpha_2 + e_{2i}) \\ &= Pr\big(e_{1i} + e_{2i} < X_i(\alpha_2 - \alpha_1)\big) \\ &= \Pr(\mu_i < X_i\beta) = F(X_i\beta), \end{aligned} \tag{2}$$

where Pr(·) is a probability function, $\mu_i = e_{1i} - e_{2i}$ is a random disturbance term, $\beta = \alpha_2 - \alpha_2$ is a coefficient vector, and $F(X_i\beta)$ is the cumulative distribution function for μ_i evaluated at $X_i\beta$. Assuming a standard normal distribution of μ_i the functional form of F is specified with a probit model where the dependent variable, y_i, will be the observed investment in an AMS. We then have:

$$\begin{aligned} & y_i^* = X_i\beta + \mu_i, \qquad \mu_i \sim NID(0,1) \\ & y_i = 1 \; if \; y_i^* > 0 \\ & y_i = 0 \; if \; y_i^* \leq 0. \end{aligned} \tag{3}$$

The difference in expected utility can change over time as the technology develops and farmers learn more about the new technology and therefore change their perceptions of how it will affect their utility. This learning can occur when observing other farmers with the new technology and when discussing the new technology with other milk producers.

4 Empirical analysis

4.1 Descriptive analysis

The data for the analysis was collected by a web survey of Swedish milk producers who deliver milk to Arla, the major Swedish dairy company, which covers about two thirds of Swedish milk producers. However, Arla only has e-mail addresses for about 60 per cent of their producers, which limits the sample. There are 4968 milk producers in Sweden (Swedish Board of Agriculture 2012a) and the questionnaire was sent out to 2439 of them, but only about 2200 of the e-mail addresses (44 per cent of the population of dairy farmers) were actually working.

Of the 2200 questionnaires that were sent out 799 responses were received which gives a response rate of 36 per cent. However, not all of the responses were complete and the final sample was reduced accordingly. 734 farmers answered the question “Have you installed/thought about installing an AMS at the farm?” and Table 1 describes the distribution of the answers to this question and summarizes the number of cows for each of the different response classes.

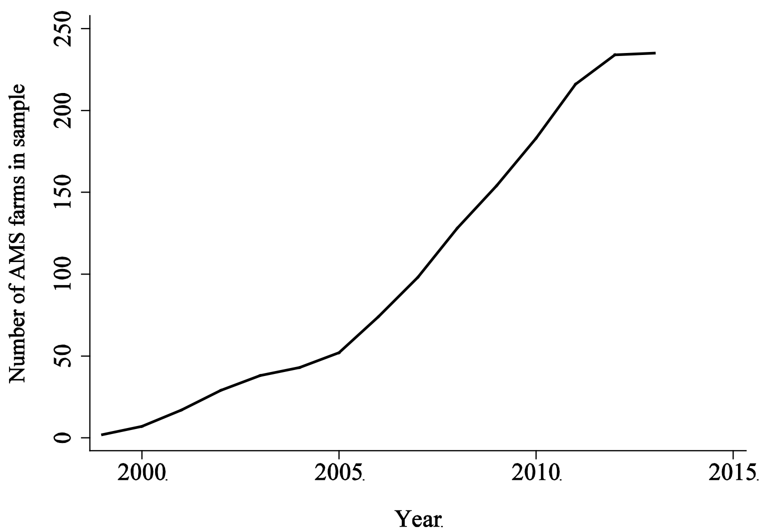
Almost 34 per cent of the respondents either installed an AMS or decided to do so, while 40 per cent had not considered it. Three farms sold a previously installed AMS. Two of these farms had a fire in the AMS, which made it less profitable, and the third farm did not specify the reason. The farms that installed or decided to install an AMS were in general larger in terms of the number of cows than the farms that had not yet decided, decided against or not considered at all.

Table 1. Distribution of farms according to AMS decision

	Observations		Number of cows			
			Mean	Sd.	Min	Max
Have installed AMS	235	(32.02 %)	116	85	40	700
Have ordered AMS, not yet installed it	8	(1.09 %)	131	85	29	240
Have decided to install, not yet ordered it	4	(0.54 %)	130	79	40	230
Installed an AMS, but sold it	3	(0.41 %)	227	75	140	270
Thinking about installing an AMS	79	(10.76 %)	75	44	14	260
Thought about installing an AMS but decided against	110	(14.99 %)	98	131	16	1250
Have not considered it	295	(40.19 %)	63	64	2	500
Total	734	(100 %)	88	87	2	1250

The farmers were also asked to state the year of the installation of the first AMS at the farm. Figure 1 shows the number of AMS farms in the sample for the years 1999 to 2013. Because the survey took place in the spring of 2013, only one farm installed an AMS in 2013.

Figure 1. Farms with AMS



Regarding the reasons for installing an AMS, Table 2 shows the share of farmers (that installed or decided to install an AMS) who agree or strongly agree with different statements concerning the importance (measured on a five-point Likert scale) of these possible reasons for the decision to install an AMS. Almost 100 per cent agree that improving the work environment is an important reason for installing the AMS. Although the majority agree with most of the statements, the two other reasons with which the farmers agree the most are to get more time for family and friends and for other business. In line with earlier findings on the AMS, the adoption decision seems to be driven mainly by non-profit-related factors (even though one could argue that the choice between work and leisure is based on economic aspects). However, even if the farmers do not invest foremost to increase profitability (64 per cent still agree that this is an important reason), they do it to get more time for other business. Saving time on the milking process means the farmer can increase his or her income by having a part-time job or by diversifying the production at the farm and hence increasing total profitability. One should also keep in mind that the answers to this question reflect the farmers' recollection of their reasons and that their memories could be influenced by the effects of the installation.

Table 2. Important reasons for installing AMS

	Number of respondents	Agree or strongly agree, share
Improve work environment	232	99.57 %
More time for family/friends	233	87.55 %
More time for other business	233	86.27 %
Improve cow health	228	72.37 %
Increase production	229	72.05 %
Decrease need for hired labour	229	69.87 %
Time to replace old milking system	230	65.65 %
Increase profitability	230	63.91 %
Decrease risk of lack of competent labour	227	54.63 %
Another milk producer has installed an AMS	229	33.62 %

One of the advantages of this study is that it has also asked those that have thought about installing an AMS, but decided not to, how they came to this decision. Table 3 shows the share of these farmers who agree or strongly agree with different possible reasons not to install an AMS. It is interesting to see that, when deciding not to install an AMS, the profit-related aspects are the most important. Most farmers agree that important reasons for not adopting the AMS are that it is too expensive and requires other large investments. The questionnaire included the possibility of stating other reasons, and recurring statements were limitations in land holdings, problems with grazing and a general perception of low profitability in milk production, which make it difficult to invest.

Table 3. Important reasons for not installing an AMS

	Number of respondents	Agree or strongly agree, share
Too expensive	100	82.00 %
Demands large complementary investments (reconstruction etc)	99	73.74 %
Difficulties financing the investment	100	60.00 %
Do not want to be disturbed by alarms at any time	98	59.18 %
Unsure about the effect on milk quality	98	50.00 %
Less contact with the cows	98	50.00 %
Good access to labour	97	45.36 %
Other large investments have been made at the farm recently	95	44.21 %
Do not know enough about AMS	95	31.58 %
Too few cows	92	25.00 %
Too many cows	94	20.21 %
Been advised against by neighbours	95	12.63 %

To relate to the literature on the importance of the social network for the adoption decision, the farmers were asked to report how important or unimportant different information sources were for the adoption decision. Table 4 displays the sources of information in order of importance. It is clear that the farmers rely heavily on other milk producers for information and advice. However, only 50 per cent of the farmers in the sample state that they regularly consult other milk producers concerning decisions at the farm; on average, 3.6 other milk producers are consulted.

Table 4. Information sources that are used and reported as important for the adoption decision

	Number of respondents	Use share	Important share
Other milk producers	341	94.13 %	87.54 %
Supplier of AMS	343	93.88 %	65.84 %
Advisors	337	77.45 %	50.96 %
Internet	324	70.68 %	37.55 %
Fairs	331	81.57 %	36.67 %

Half of the surveyed farmers use advisors on a regular basis and a similar share has at least one advisor when deciding to adopt an AMS or not. This is in contrast to the results in Table 4 where 77 per cent use advisors to help with the decision. What this discrepancy is due to, we do not know. Of those that use advisors, the most common (44 per cent) is to use one advisor, but 28 per cent have used two advisors and 27 per cent have used more than two. Among those that have actually decided to adopt the AMS, 63 per cent have hired an advisor to help with the decision. However, many farmers maintain that they are not satisfied with the Swedish advisory services and that the advisors do not know enough about the AMS.

Concerning the effects of the installation of an AMS, Table 5 summarizes the farmers' perceived effects on different factors. It seems that the effects of the installation are in line with the expectations based on what the farmers see as important reasons for the adoption decision. About 95 per cent think that the quality of the work environment has increased, 59 per cent that the time for family and friends has increased and 89 per cent that the labour per cow has decreased. With an increase in production of milk per cow and a decrease in labour per cow, we would expect profitability to increase (disregarding the costs), but only 18 per cent report an increase whereas 32 per cent report decreased profitability. One could think that this distribution would differ depending on how long ago the AMS was installed, because there could be a lot of initial problems when teaching the cows how to use the AMS, but the responses are distributed in a similar way irrespective of the year of installation. Landin and Gyllenswärd (2012) suggest that the low profitability for AMS farms is probably not due to inefficiency in the technology but to the management of the milking system. This is in line with the point made by Svennersten-Sjaunja and Pettersson (2008) that the AMS is not just a new technology for milking but a new management system. Besides, as many of the farmers in this survey point out, the farmer needs to have a genuine interest in technology as well as in the cows to make production work with an AMS. However, these arguments favour the idea that we should expect higher profitability after a learning period, which we do not observe here. One could also think that the reporting of a lower profitability could depend on the general level of profitability in milk production, but then again we would probably observe different answers depending on when they installed the AMS, which we do not. In addition, despite problems with profitability, 92 per cent of the AMS farmers in the sample would recommend the AMS to other farmers. Of those that report decreased profitability, this share is 77 per cent. Another thing to keep in mind is that the reported effect on profitability concerns milk production. It could be that the farmers now have more time to spend on other production at the farm or on another job, which could increase profitability for the household even though the profitability in milk production has decreased.

Table 5. Effects from the installation of the AMS

	Increased	Not been affected	Decreased	Do not know	Not relevant	Number of respondents
Production of milk per cow:	36.12 %	34.36 %	25.55 %	1.76 %	2.20 %	227
Number of cows:	70.93 %	17.62 %	0 %	9.25 %	2.20 %	227
Labour per cow:	1.75 %	5.68 %	89.08 %	2.18 %	1.31 %	229
Number of employees:	18.06 %	40.97 %	29.07 %	1.76 %	10.13 %	227
Profitability:	17.70 %	33.19 %	31.86 %	12.83 %	4.42 %	226
Milk quality:	19.47 %	49.56 %	26.55 %	3.10 %	1.33 %	226
Time for family/friends:	58.77 %	27.19 %	8.77 %	3.07 %	2.19 %	228
Quality of the work environment:	94.69 %	2.21 %	1.77 %	0.44 %	0.88 %	226

4.2 Regression analysis

4.2.1 Variables

The model in section 3 is estimated with the dependent variable as 1 if the farmer either has an AMS installed at the farm, or has ordered an AMS that is not yet installed. For all other farms the dependent variable takes the value 0. In the questionnaire the respondents could state that they had decided to invest in an AMS but not yet ordered it. Only four farms belong to this category and because they could be treated as either having an AMS or not having one, they are excluded from the regression. Optimally, we would like to model the adoption decision, but with the data available it is only possible to model the probability of having an AMS. However, some of the variables are designed to measure the situation at the time of adoption, and some variables can be assumed not to have changed since the time of adoption. Furthermore, the current farm manager answered the questionnaire, and he/she could have taken over the position after adoption.

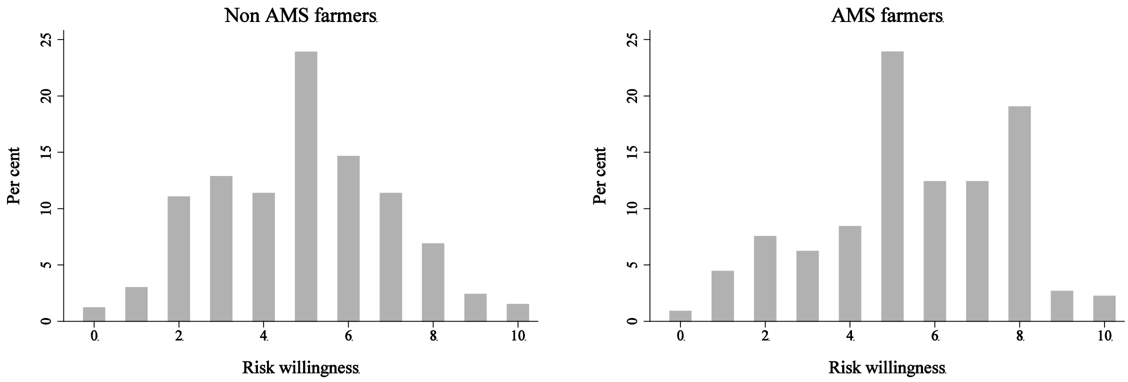
The explanatory variables are a mix of farm and farmer characteristics that could influence the probability of investing in an AMS.

The size of the farm is an important determinant of technology adoption because it is connected to factors such as credit constraint, wealth and capacity to bear risks (Feder et al. 1985). The size of the farm in terms of the number of cows is of course an important determinant for installing an AMS but it can also be that at the same time as installing an AMS the farmer also increases the number of cows in order to use the AMS at full capacity. Due to the functioning of the AMS there might be a decreasing effect of size, and we, like Sauer and Zilberman (2012), therefore include a squared variable. We also include a variable for the share of land that is under tenure, because a large share of tenured land could increase insecurity about the future and the possibility of maintaining or increasing production levels (Sunding and Zilberman 2001).

The farmer's education and experience are often positively correlated with the use of new technology (Feder et al. 1985). We measure education on a four-level scale from practical experience to university studies in agriculture. However, to better separate out a possible effect we redefine this variable as taking the value 1 for high school or university studies and the value 0 for practical experience or basic studies. Many farmers state life-long experience of milk production in the questionnaire, which makes experience quite correlated with age, and we therefore also control for this aspect in the estimation. The expected effect of age on technology adoption is ambiguous. On the one hand, an older farmer has more experience and is therefore better at appreciating the characteristics of the new technology earlier; on the other hand, older farmers are often more risk averse and work with shorter time horizons and are therefore less likely to adopt new technologies (Adesina and Baidu-Forson 1995, Gillespie et al. 2007). We asked the farm manager for age and experience at the time of the survey and, from this information, calculated the values for the time of adoption. In addition, for those that state life-long experience, we have calculated years of experience from the age of 15.

Investments in new technology are often connected to risk and uncertainty about the technology's profitability. A general idea is that a person who is more willing to take risks is more likely to be an early adopter of new technology. Following Dohmen et al. (2011), we measure risk willingness with a question asking the respondent to give us an assessment, on an eleven point scale (where 10 means risk loving and 0 means risk averse), of his or her willingness to take risks concerning decisions about the farm. Dohmen et al. (2011) show that risk willingness is context-specific and that this subjective assessment corresponds rather well with the behaviour in experiments. Looking at the distribution of the responses to this question among adopters and non-adopters of AMS, as displayed in Figure 2, it seems that the farmers who have installed an AMS are more risk willing than those that have not.

Figure 2. Risk willingness



The existence of off-farm income or income from other production at the farm could also be a way of making the farmer less risk averse in terms of investments in new technology (Thirtle et al. 2003). It could also be that an investment in an AMS would give the farmer more time to spend on these other work tasks, thus making more money (Sauer and Zilberman 2012). However, both positive and negative effects of off-farm income on adoption decisions are found in the literature.

One factor that affects the expected utility of a possible investment in an AMS is what the farmer thinks about the future in milk production. We try to capture this aspect with questions on the farmer's beliefs about profitability in milk production in the following five years, and (for family farms) on whether the farmer has a successor or not. Potter and Lobley (1992) show that the existence of a successor has an important influence on the behaviour and decisions made by older farmers. Farmers with successors are more likely to invest in capital and intensify the production than farmers without successors.

Interest in new technology and new production techniques is measured by a question on how often the farmer changes his or her cell phone, if there are other work tasks at the farm that are (or were before adoption) automatized (e.g. automatic feeding) and whether the milk production is organic or conventional. Sauer and Zilberman (2012) argue that experiences with the adoption of new farming practices such as organic farming could influence the current adoption decision. They also find a positive effect of organic production on the adoption of the AMS, but Meskens et al. (2001) point out that an organic farmer might not want a high level of technology even though organic farming is more labour intensive and thus he or she could profit more from an investment in an AMS.

Because the investment in an AMS is large, it could be facilitated by receiving investment aid. In the rural development programme, one of the sections for investment aid is called modernisation of agricultural holdings. Of the 834 instances of investment aid that were paid out to milk producers in Sweden during 2007-2009, a third (and half of the total amount) was used for investment in an AMS with or without new construction or rebuilding (Swedish Board of Agriculture 2012b). Both Sauer and Zilberman (2012) and Heikkilä et al. (2012) find that receiving investment aid has a positive effect on the adoption of AMS. We hence asked the farmers whether they have received investment aid or not during the past 15 years. However, there could be a problem of endogeneity with the investment variable. In this sample, 96 per cent of the AMS farmers have received investment support compared to 54 per cent of the other farmers and 77 per cent of farmers with milking systems that were installed after 1997. A farmer only receives investment support if he/she goes through with the investment, and the large share of support receivers could indicate that there are no difficulties in receiving support.

The AMS was launched as a way of decreasing labour costs and labour management, therefore, we include a variable for the share of hired labour in total labour, following Sauer and Zilberman (2012).

To try to capture some aspects of the effect of the farmer's social network we included a question on how many AMS milk producers the farmer knew (at the time of the survey). This question could also indicate whether or not the farmer had seen the system in practice, which could be helpful when deciding whether to invest or not. Because many farmers used an interval (e.g. 10-20) to answer this question, we have divided the answers into four interval categories[1]. We also asked if there were any other milk producers the farmer regularly asked for advice concerning decisions at the farm. And then the farmer described up to two of these people in terms of distance from the farm, friend or family, how many cows he or she had and if this person had installed an AMS or not. As mentioned before, half of the farmers said that they regularly consulted other farmers and the average was to consult 3.6 other farmers. From this question we calculate the share of AMS farmers of these one or two farmers that the farmer mentioned. We hope to capture the most important informal advisors, but, of course, there is a lot of uncertainty around this variable.

We also include regional dummies to control for possible regional effects.

4.2.2 Selection

A major problem when using survey data is dealing with sample selection. First it is a question of whether the survey is sent out to a random sample of the population and, second, a question of non-response bias – those that respond to the survey differ from those who do not. There is room in the survey for both of these problems. As mentioned before, Arla covers

[1] These categories are: 1: 0-4, 2: 5-9, 3: 10-19, 4: 20-100.

about two thirds of the Swedish milk producers and this group is mainly based on geographical area. In many places a farmer cannot choose to which dairy company he/she delivers the milk. In this sense, there is no reason to believe that this is not a random sample. However, we only target those farmers who have given their e-mail address to Arla; their farms are in general larger farms. The amount of delivered milk to Arla is on average almost twice as large for the farms with e-mail addresses compared to the farms without. Still, because the AMS is intended for farms with at least 60 cows, we cover the relevant population in general.

Table 6. Descriptive statistics of regression variables

	N	Mean	Sd	Min	Max
AMS (1=Yes, 0=No)	554	0.40	0.49	0	1
Family farm (1=Yes, 0=No)	601	0.91	0.29	0	1
Existence of successor (1=Yes, 0=No)	543	0.24	0.43	0	1
Off-farm income and/or other farm income (1=Yes, 0=No)	538	0.71	0.45	0	1
Experience at adoption	567	26.33	12.39	0	65
Age at adoption	578	48.42	10.90	15	72
Education (1=high school or university studies, 0= practical experience or basic studies)	573	0.58	0.49	0	1
No. of cows	568	105.42	91.98	40	1250
Share of tenured land	540	0.53	0.28	0	1
Share of hired labour	521	0.44	0.42	0	1
Risk (0=Risk averse, 5=Neutral, 10=Risk loving)	530	5.12	2.19	0	10
Cell phone change (1=more often than when the old one breaks down, 0=when the old one breaks down)	528	0.15	0.36	0	1
Belief of profitability nearest 5 years (1=Increase, 0=Unchanged, decrease or unsure)	531	0.29	0.46	0	1
Organic (1=Yes, 0=No)	555	0.20	0.40	0	1
Automation (1=Yes, 0=No)	532	0.68	0.47	0	1
Investment support (1=Yes, 0=No)	551	0.77	0.42	0	1
Advisors regularly (1=Yes, 0=No)	532	0.52	0.50	0	1
Known milk producers with AMS (1=0-4, 2=5-9, 3=10-19, 4=20-100)	537	2.50	1.00	1	4
Share of milk producers with AMS of those that the farmer asks for advice	280	0.46	0.38	0	1

The possible existence of non-response bias is a more problematic issue. With a response rate of 36 per cent we would like to know something about the representativeness of the respondents. Concerning the adoption of AMS, we do not know anything about the number of AMS adopters in the sample that received the questionnaire, but we do know that there is a larger share of AMS farms among the respondents than in the total population. At the end of 2011, about 20 per cent of the Swedish milk producers milked their cows in an AMS (Landin and Gyllenswärd 2012, Swedish Board of Agriculture 2012a), and 32 per cent of the farms in the sample for this study use an AMS. But because the survey targeted larger farms in general, and the AMS is intended for larger farms, the overrepresentation is probably not as great as one may first think. In addition, at the time of the survey there were probably more AMS farms than there were in 2011. In our sample, 8 per cent of the AMS farms adopted the technology in 2012 or 2013. However, due to the lack of information on the survey sample we cannot deduce if there actually is a nonresponse bias or not.

Another problem of survey data is of course the problem of mistyping (especially in web surveys) and misinterpretation of the questions. Some responses are conflicting and we have eliminated these responses wherever possible.

Not all of the responses are complete, as can be seen in Table 6 which displays descriptive statistics of the possible regression variables in the sample limited to farms with at least 40 cows. This limitation is based on the functioning of the AMS in terms of the number of cows it is suited for, and that the smallest AMS farm in the sample has 40 cows.

4.2.3 Estimation

We estimate the probability of having an AMS with the variables outlined in section 4.2.1. Table 7 reports the regression results (average marginal effects of probit estimation) where column 1 contains the results for all farms with at least 40 cows. We find a significant negative effect of both experience and age. A positive effect is usually expected from experience, which makes the negative effect a bit puzzling. As mentioned before, there is a high correlation between experience and age, and it could be that the age effect is so much stronger that we also find a negative effect of experience. It could also be that a more experienced farmer sees that this technology is not profitable and therefore does not adopt. Still, this result stands in contrast to that of Sauer and Zilberman (2012), who find a positive effect of experience on the adoption of AMS. We further find the education variable to be insignificant whereas we find a significant effect of the number of cows at the farm, but the effect is small and diminishing.[2]

The coefficient for the share of tenured land is negative and significant on the 10 per cent level, supporting our expectations that a larger share of tenured land creates insecurity that inhibits investments. Many farmers have also stated, in the questionnaire, that a reason for not installing an AMS is the problem of limited land holdings and problems of tenure. The coefficient for the share of hired labour in total labour is insignificant. However, there is some uncertainty around this variable. There are some indications of misinterpretations of this question[3]; besides, it was measured at the time of the survey and we would expect it to have more effect on the adoption decision.

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[2] Due to the problem that farmers may increase the number of cows at the time of adoption we have also investigated the use of the number of hectares as the size variable (even though the same problem might arise with this variable) but the coefficients for these variables are insignificant.

[3] The respondents were asked to first state the number of employees at the farm and then how many of these were family members. However, sometimes they reported more family member employees than the total number of employees. These responses are easy to detect, but there is the possibility that a farmer who reported e.g. two family member employees and two as the total number of employees actually means that there are four people working at the farm, and these misinterpretations are impossible to detect.

Table 7. Estimation output (Average marginal effects)

	(1) At least 40 cows	(2) Without investment	(3) Family farms	(4) Considered AMS	(5) With consulted	(6) Without labour, AMS
Experience	-0.005*	-0.004	-0.005*	-0.001	-0.004	-0.003
	(0.003)	(0.003)	(0.003)	(0.003)	(0.004)	(0.003)
Age	-0.008**	-0.010***	-0.010***	-0.012***	-0.008**	-0.012***
	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)	(0.003)
Education	-0.060	-0.077*	-0.086*	-0.103*	-0.066	-0.046
	(0.041)	(0.042)	(0.045)	(0.054)	(0.053)	(0.040)
Cows	0.001**	0.001***	0.001**	0.002***	0.001	0.002***
	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)	(0.000)
Cows squared	-0.000**	-0.000***	-0.000	-0.000***	-0.000	-0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Tenure, share	-0.145*	-0.116	-0.047	-0.171*	-0.098	-0.112
	(0.076)	(0.078)	(0.084)	(0.102)	(0.109)	(0.076)
Hired labour, share	0.004	-0.007	0.039	-0.035	0.025	
	(0.047)	(0.050)	(0.054)	(0.062)	(0.060)	
Risk	0.001	0.002	-0.009	-0.007	0.024*	0.008
	(0.009)	(0.010)	(0.010)	(0.012)	(0.013)	(0.010)
Belief profitability	0.106**	0.118***	0.094**	0.130**	0.161***	0.111***
	(0.043)	(0.045)	(0.047)	(0.054)	(0.053)	(0.043)
Cell phone change	0.011	0.007	0.022	-0.027	-0.143**	0.005
	(0.051)	(0.054)	(0.059)	(0.065)	(0.061)	(0.054)
Organic	0.083*	0.105**	0.104*	0.133**	0.040	0.149***
	(0.049)	(0.052)	(0.053)	(0.065)	(0.071)	(0.050)
Automation	-0.050	-0.071*	-0.049	-0.092*	-0.088	-0.084**
	(0.041)	(0.043)	(0.045)	(0.055)	(0.057)	(0.042)
Investment support	0.370***					
	(0.055)					
Advisors, regularly	-0.122***	-0.117***	-0.113***	-0.084	-0.077	-0.082**
	(0.039)	(0.040)	(0.041)	(0.051)	(0.053)	(0.038)
Known AMS farmers, 5-9	0.042	0.089	0.097*	0.075	0.048	
	(0.058)	(0.057)	(0.058)	(0.087)	(0.083)	
Known AMS farmers, 10-19	0.126**	0.190***	0.209***	0.087	0.061	
	(0.057)	(0.058)	(0.059)	(0.087)	(0.098)	
Known AMS farmers, 20-100	0.276***	0.342***	0.373***	0.295***	0.218**	
	(0.069)	(0.069)	(0.070)	(0.093)	(0.109)	
Off-farm income or other income at the farm			0.001			
			(0.048)			
Successor			0.105*			
			(0.055)			
Consulted milk producers with AMS, 50 %					0.197***	
					(0.058)	
Consulted milk producers with AMS, 100 %					0.459***	
					(0.072)	
Observations	458	458	420	319	236	519

Robust standard errors in parentheses. ***,**,* Coefficients are significant on the 1, 5 and 10 % levels respectively. Regional dummies not reported. Average marginal effects are reported.

Farmers who believe in profitability in milk production are more likely to install an AMS, whereas we find no significant effects of risk, or the variables for technology interest in terms of how often farmers change their cell phone, and if there are daily tasks that are (or were before adoption) automatized. However, many farmers have stated that you need to have an interest in computers if you are planning to install an AMS. An organic milk production could also be a sign that a farmer is open to new production techniques, and we find this variable to be positive, but only significant on the 10 per cent level.

We do not report the regional dummies, but these are not significant, either separately or jointly, indicating that there does not seem to be any regional effects.[4]

The farmers who regularly use advisors have a lower probability of having an AMS. However, we cannot deduce if this result is due to advisors advising against the AMS (possibly due to low profitability), or if the farmers who regularly use advisors are different in their investment behaviour compared to the farmers who do not use advisors.

Farmers who know many other AMS farmers are more likely to have an AMS themselves. In Table 8 we present the predicted probabilities of having an AMS for the different categories of known AMS farmers, holding the other variables at their means. Looking at these results we see that the probability of having an AMS is almost three times as high for farmers knowing more than 20 AMS farmers compared to those knowing fewer than five. However, this result could reflect the fact that once you have installed an AMS you get to know many other AMS farmers.

Table 8. Predicted probabilities of having an AMS for different numbers of known AMS farmers, other variables at means

Known AMS farmers	Predicted probability	Std. Err.	z	P>z
0-4	0.20	0.05	4.06	0.00
5-9	0.25	0.05	5.41	0.00
10-19	0.35	0.04	7.98	0.00
20-100	0.56	0.07	8.43	0.00

Farmers who have received investment support have a higher probability of installing an AMS. However, due to the seemingly simplicity of receiving investment support, this finding does not necessarily say that the investment would not have been made without the investment support. Earlier findings from the midterm evaluation of the Rural Development Programme in Sweden show e.g. very limited effects of the investment support on investments (Swedish University of Agricultural Sciences 2010). Besides, it is likely that this variable is endogenous and we therefore exclude it in the following.

To investigate the results further we re-estimate the regression for different subsamples, and with some different variables. First, we exclude the variable for investment support and column 2 displays these results. Here the experience variable is insignificant, as is the share of tenured land. Nonetheless, the education variable is now significant (on the 10 per cent level) and negative, indicating that those with higher education may be better at recognising the flaws of the technology and understanding that it is difficult to have a profitable production

[4] In a few other specifications of the regression model, we reject the notion that all of the regional dummies are zero, but in general there is not much support for regional effects.

with it. Moreover, the coefficient for automation is now significant on the 10 per cent level and negative, indicating that if there are tasks in the daily work that are automatized, then the farm is less likely to have an AMS. This result is quite counterintuitive, but could indicate that the farmer either automatizes these tasks at the same time as installing the AMS, or if he/she has chosen not to install an AMS, instead automatizes other work tasks than the milking process in order to facilitate the daily work. Otherwise the results are similar to the ones in column 1, indicating that the inclusion of investment support does not seem to have a large impact on the other variables, but we will still continue to exclude this variable.

Column 3 shows the results for family farms (which reduces the sample by 38 farms), and it is now possible to include the variables for the existence of a successor or not, and the existence of off-farm income or other income from the farm (other than from milk production). This latter is insignificant whereas the coefficient for successor is significant (on the 10 per cent level) and positive, indicating that the existence of a successor gives an incentive to invest in the production. Many farmers have also reported in the questionnaire that it is not worth investing because there is no one to take over the production, and that production with AMS is more suitable for the younger generation. Concerning the other variables, the results are quite similar to the ones reported in column 2 except that the coefficient for experience is significant (on the 10 per cent level) and the coefficients for automation and the squared cow variable are now insignificant.

Column 4 only includes farms that have considered installing an AMS, resulting in a sample of 319 farms. The share of tenured land here is significant and negative and the coefficient for regular use of advisors is insignificant; otherwise the results are very similar to those reported in column 2.

As mentioned before, there was a question in the survey about whether the farmer discusses farm decisions with other milk producers, and whether or not these farmers have installed an AMS. Because it is only possible to describe two other farmers, the possible outcomes of the variable for the share of consulted farmers with an AMS are 0, 50 or 100 per cent. Therefore this variable is transformed into dummy variables in the regression and the results are displayed in column 5. Many farmers have not answered this question or have reported that there are no other farmers with whom he/she discusses decisions, which limits the sample to 236 farms. In this sample the coefficient for the risk variable is significant and positive and the coefficient for cell phone change is significant on the 10 per cent level and negative, which is surprising. Furthermore, the coefficients for experience, education, number of cows, organic production, automation and advisors are now insignificant, possibly due to the reduced sample. In addition, this regression gives some support to the importance of the behaviour of the milk producers in the farmer's social network. The coefficients for these variables are positive and significant on the 1 per cent level, whereas only the largest category of known AMS farmers is now significant. This result indicates that it is the behaviour of these consulted farmers that is important for the adoption decision. However, it could be that it is the farmer in question that has influenced other milk producers to invest in an AMS, but then that also supports the idea of the importance of the social network. It could also be that because you have installed an AMS, you primarily turn to other AMS farmers for advice.

Table 9 reports the predicted probabilities of having an AMS for the different categories of consulted farmers with AMS (holding the other variables at their means). If both of the described consulted milk producers have an AMS the probability that the individual farmer also has it is 0.76 whereas it is only 0.14 for a farmer whose consulted farmers do not have an AMS.

Table 9. Predicted probabilities of having an AMS for different shares of consulted farmers with AMS, other variables at means

Share of consulted farmers with AMS	Predicted probability	Std. Err.	z	P>z
0 %	0.14	0.05	3.22	0.00
50 %	0.40	0.06	7.23	0.00
100 %	0.76	0.07	10.99	0.00

In column 6 we have eliminated the variables for the share of hired labour and the number of other known AMS farmers in order to increase the sample size (there are many missing observations on these variables). The coefficient for education is insignificant; otherwise, the results are very similar to those in column 2 (some variables are now significant on a higher significance level).

In sum, the results are generally in line with earlier findings on technology adoption, and more specifically on the adoption of AMS. The age of the farmer is negatively associated with the probability of having an AMS, whereas farmers who believe in profitability in milk production in the near future, and who know many other AMS farmers, have a higher probability of having an AMS. For family farms we also find a positive effect of the existence of a successor. Even though the sample is limited to farms with at least 40 cows, we find some evidence for a small positive but diminishing effect of the size of the farm. Organic production also seems to have a positive effect whereas there are indications of negative effects from experience, education, share of tenured land and regular use of advisors. In all, the results seem to be quite robust; the coefficients remain, in general, similar in size and significance levels over the different specifications, except for the coefficients for experience, education, tenure, automation and advisors. The robustness of the results is further investigated by means of different diagnostics tests for possible outliers and goodness of fit measures, and we conclude that the results seem robust in this sense as well.[5] However, one should keep in mind the fact that the results are based on the farm and farmer characteristics at the time of the study and not at the time of the adoption decisions. Some of the characteristics might have changed since the decision, and even the farm manager could be new, but there is no way of dealing with this problem.

5 Conclusions

The use of AMS is spreading both in Sweden and in the world. In general we would expect new technology to increase productivity and make production more efficient, and this is what

[5] For example the model passes the Hosmer-Lemeshow goodness-of-fit test and the predictive power given by the area under the ROC line is 0.82 (for the specification in column 2).

Heikkilä et al. (2012) find in their study on AMS in Finland. However, of the AMS farmers in our study, only 18 per cent reported increased profitability, whereas 32 per cent reported decreased profitability. But 36 per cent reported an increase in the production of milk per cow. Hence, there is some ambiguity concerning the efficiency of this new technology. One should also keep in mind that this study only covers 16 per cent of all Swedish milk producers and that there could be some bias in the results.

One thing that is very clear is that production with an AMS improves the work environment. This is what farmers agree on most as an important reason for the installation of an AMS, whereas the cost of the AMS is the reason for *not* installing an AMS. This result indicates that, even though expected profitability is important, the type of technology that interests farmers today is one that facilitates the daily work and makes it less physically heavy. The development of the AMS has been driven by rising labour costs and therefore aimed at increasing profitability for the farmer by substituting labour for capital. However, the results of this study indicate that there are problems of profitability, which means that the adoption of this technology may not be a means to increase competitiveness. For those who can afford it, it is a way to improve the work environment and to have more flexible work hours.

From the probit estimation and the descriptive analysis we conclude that the behaviour and advice of other milk producers is important for the individual farmer's decision to adopt the new technology or not. Compared to earlier studies, we have more accurately studied the farmers' social network because we asked them to state their own network, instead of just assuming that the network consists of the neighbours. But, because we measure these variables at the time of the survey and not at the time of the decision, the positive relationship could reflect a changed behaviour of the farmers since the time of adoption.

It is common to find positive effects of experience and education in adoption studies; the idea behind this result being that the more experienced and better educated farmer is better at appreciating the new technology and therefore adopts earlier. There are indications in this study of negative effects from experience, education and regular use of advisors, which could instead signal that these farmers or advisors are better at foreseeing the potential problems concerning profitability with this new technology, and therefore do not adopt.

As mentioned before, half of the amount of investment support within the rural development programme in Sweden for the period 2007-2009 was for investments in AMS. One of the goals of this support is to improve the work environment, and in that sense the investment support may be seen as successful. However, the main purpose is to speed up the firms' adjustments to new market conditions and hence to increase competitiveness in the agricultural sector. In this sense the support seems less successful and it is questionable if it should be given to investments in AMS.

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