QUANTIFYING THE EFFECTS OF SOW-HERD MANAGEMENT INFORMATION SYSTEMS ON FARMERS' DECISION MAKING USING EXPERIMENTAL ECONOMICS

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A pilot experiment was conducted to yield insight into whether laboratory experiments can be used as an alternative to surveys for determining the profitability of management information systems (MIS) in sow farming. In total, eighty-six sow farmers, including fifty-one farmers from an earlier survey study, participated in an individual decision-making experiment, which was executed in a quasi-experimental, nonequivalent control, pretest/posttest design. In an MIS group, MIS estimates were derived by within-subjects comparisons of decision quality with and without MIS features. A baseline group was included to control for learning or exhaustion effects during an experimental session. Subjects receiving MIS features significantly improved their decision making whereas subjects without MIS features did not. Correlation between MIS estimates of the survey study and MIS estimates of the experiment was not significant.

Key words: individual decision-making experiment, Markov decision programming, pig farming, value of management information systems.

During the last decade, developments in electronic data recording and processing systems have provided strong support for farmers' efforts to improve farm performance. Management information systems (MIS) are more advanced systems "designed to provide daily production information on the individual animal level that is of potential value in making management decisions" (Boehlje and Eidman). MIS record and structure the bulk of individual animal data on a farm, calculate certain key figures, and produce farm overviews and working and attention lists. These MIS attributes give farmers the opportunity to identify deviations in performance sooner and to identify other, less obvious deviations as well. Moreover, calculation of key figures and specific analyses of farm data provide new types of information that can improve decision making.

Verstegen et al. (1995a) conducted a survey study on the profitability of MIS in sow farming. Using a quasi-experimental nonequivalent time-series design, they showed that after MIS adoption farmers raised 0.56 piglets per sow per year more than before (adjusted for farm variation, learning, and trend effects). The estimated MIS profit of $15 to $17 per sow per year meant a return on investment of 220% to 348% and an improvement in net returns to labor and management of 7.7% to 8.7%.[1] However, the small number of observations per farm obstructed in-depth analysis of the relationship between MIS use and individual farm performance. A controlled field experiment would have provided more opportunities for in-depth analyses but could not be done because the MIS under

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[1] Return on investment of MIS = MIS profit divided by MIS investment costs; net return to labor and management = net farm profit plus compensation for labor and management.

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study were already in use, thus making impossible a random assignment of farmers to MIS treatment and control groups (Verstegen et al. 1995a).

This article reports a pilot experiment intended to yield insight into whether laboratory experiments can be used as an alternative to surveys for determining the profitability of MIS in sow farming. Experimental economics is a means to benefit from the strength of field experiments (such as control of intervening variables) and to overcome some of their practical limitations (such as pre-audit assignment of subjects and high labor and money requirements). A basic precept is that their results carry over to the more complex natural environment (Smith, Davis and Holt). If the experimental economics approach proves to be a good alternative to a survey study, it may be used for (*ex ante*) evaluation of new MIS systems and, possibly, other information services.

In this study, a comparison is made between experimental and survey MIS estimates, both derived from the same pig farmers. An overall effect of MIS is found in both the experiment and the survey study. However, the two MIS estimates are not significantly correlated. Problems with the experimental design and/or biases in survey MIS estimates due to exogenous changes on farms other than MIS use, and differences between the laboratory and the natural environment in levels of communication and decision-making routine, are the most likely explanations for the uncorrelated estimates.

Outline of the MIS Evaluation Experiment

In sow farming, MIS support sow replacement decisions and thus contribute to a reduction in the average number of unproductive days per sow.[2] The risk and payoff per individual sow replacement decision are low but the quality of the decision-making process significantly affects farm results because of the large number of replacement decisions that must be made. In the experiment, these characteristics are included in the abstract experimental economics analogue of the sow replacement problem presented as an investment project selection problem.[3]

Investment Project Selection Problem

Instead of making sow replacement decisions, subjects in the experiment decide whether to keep or replace investment projects. Appendix 1 shows the parallels between the abstract and the natural decision problem. An experimental year is defined in which subjects decide on one group of fifteen projects first, and then on a second group of fifteen projects.[4] In the next experimental year, they again decide on the first fifteen projects, and so on. This procedure is repeated for nine experimental years per treatment. Time available for decision making is limited (to resemble its opportunity cost in sow farming). Terminated projects are replaced by new projects to keep the total number of projects per group at fifteen. Each experimental year the number of production years of a project increases by one; e.g., a project with four production years in experimental year 1 has five production years in experimental year 2.

Yearly production results are sampled from a normal distribution around a project's production potential. The more years a project has produced, the more (imperfect) information subjects have about its production potential. The production potential of an investment project in the experiment consists of two properties: the number of production weeks in a production year (PW) and the yield, i.e., the number of points that can be scored per production week (Y/PW).[5] The property PW is constant over time and has two levels only, which are "many" and "few." The difference between the values of these levels equals one standard deviation of the normal distribution around PW.

Analogous to the (age-related) trend in litter sizes of sows, Y/PW expectations of projects change over time, with a maximum value in the fourth and fifth production year. Two levels ("high" and "low") are used; these

[2] Pig farmers in the survey study of Verstegen et al. 1995a stated that most MIS benefits originate from this reduction.

[3] The personal computer software was developed for this experiment by Otto Perdeck at the Centre for Research in Experimental Economics and Political Decision Making (CREED), University of Amsterdam.

[4] Parameters, such as the time for decision making and the group sizes were determined in pilot tests, executed with staff members and (under)graduate economics students of both the University of Amsterdam and the Wageningen Agricultural University.

[5] The coefficients of variation of those properties match their natural counterparts.

levels also differ by one standard deviation. With equal probabilities, a project has the property "many" or "few" production weeks in a production year throughout its lifetime. Similarly, a project has 0.5 probabilities of generating "high" or "low" yields per production week. Consequently, projects' production potentials define four different project types with a 0.25 probability of occurrence: HM (high Y/PW; many PW), LM (low Y/PW; many PW), HF (high Y/PW; few PW), and LF (low Y/PW; few PW).

The project types and their probabilities were explained to the subjects in the experiment.[6] With this information, subjects can form beliefs about the production potential of a project by relating its (sampled) production results to the given distributions. If a project has a relatively high yield per production week during many production years, it will likely have the property "high Y/PW." If this project repeatedly produces low yields per production week, it will likely have the property "low Y/PW." The same logic applies to the property PW. If a subject believes that the production potential (formally, the expected future profitability) of a project exceeds that of an unknown new project, the best decision is to keep the project; otherwise, replacing is the best option. If a subject is uncertain about a project's potential, the decision to keep the project will reduce the uncertainty through observation of the project's production results in the next year. This can improve the replacement decision in the next year but it also includes the risk of having kept a bad project one year too long. The subjects' task is to adequately form beliefs about a project's production potential and consequently keep the projects with a relatively high production potential and replace the projects with a relatively low production potential.

With and Without MIS

In the natural situation, MIS support farmers in making sow replacement decisions by converting raw production data into more manageable performance indicators, and by structuring and sorting production data in herd overviews. Therefore, MIS effects on farmers' decision making result from data processing, not from the provision of additional data. In the experiment, MIS are evaluated by looking at differences in subjects' decision making between an experimental treatment "with" and a treatment "without" processing of investment project data. Appendix 2 describes the analogy between the economics experiment and the natural situation, "without" and "with" MIS.

In the "without MIS" treatment in the experiment, for each individual investment project subjects get a full-screen project card displaying the project's production results in the past. Yearly production data include the average yield per production week (Y/PW) and the number of production weeks (PW). PW is indicated by production periods with starting and ending dates, e.g., the 2nd of February until the 6th of December. Only the last ten production years are displayed, although investment projects can be kept longer. Subjects can browse through fifteen projects and mark individual projects for replacement. A decision to replace is visualized by a red cross drawn through the project card. Subjects can undo this decision (remove the red cross) until a time limit of 120 seconds is exceeded (see appendix 1).

In the "with MIS" treatment, subjects receive project cards that are similar to the ones in the "without MIS" treatment. However, average values are added and the starting and ending dates, which delineate the production period in a production year, are converted into the actual number of production weeks (PW) in a production year. Furthermore, the total yield per year (Y), which is the product of the number of production weeks (PW) and the yield per production week (Y/PW), is calculated for each project and each (displayed) production year. This figure is displayed on the individual project cards together with averages per year of PW, Y/PW, and Y. Finally, subjects can request overviews of fifteen projects that contain the averages per year of PW, Y/PW, and Y, and are sorted on Y or on the number of production years (age of projects).

Experimental Design and Procedure

MIS effects are estimated in a quasi-experimental, nonequivalent control, pre-test/post-test design (Weiss, Verstegen et al. 1995b), involving an MIS and a baseline group, as shown in table 1. Subjects in the MIS group start with a "without MIS" treatment (M1)

[6] An English translation of the instructions as well as copies of the figures that were used to explain the distributions of the production parameters are available upon request.

Table 1. Outline of the Experimental Sessions for MIS Evaluation

	Instructions[a]	Training Period	First Treatment	Coffee Break	Instructions	Training Period	Second Treatment	Subject Payment
No. of Exp. Years		4	9			3	9	
	X	X	M1 Raw production data (Project file 1)	X	X	X	M2 Converted data + overviews (Project file 2)	X
Baseline group	X	X	B1 Raw production data (project file 1)	X			B2 Raw production data (project file 2)	X

[a] Indicates includes a comprehension test.
Note: X indicates applicable to this group; — indicates not applicable to this group.

and continue with a "with MIS" treatment (M2); subjects in the baseline group get two "without MIS" treatments (referred to as B1 and B2). Treatments M1 and B1 are identical and provide the pre-test values in the experiment. The "with MIS" treatment (M2) and the "without MIS" treatment (B2) provide the post-test values. MIS effects are estimated by subtracting the pre-test values from the post-test values within the MIS group, i.e., M2 − M1. The baseline group is included for controlling autonomous or exogenous changes in decision making over time, e.g., learning or exhaustion effects. These effects are estimated by subtracting pre-test values from the post-test values within the baseline group, i.e., B2 − B1.

Each treatment is run for nine experimental years, but, to avoid possible end-game behavior, time horizons are not announced to the subjects. An experimental session ends after the second treatment, when each subject is paid in private an amount of cash equal to his or her earnings in the experimental session.

Decision Quality

Quality of decision making is assessed by comparing subjects' decisions to those implied by the theoretically optimal decision-making strategy (assuming risk neutrality). This optimal strategy is calculated with a stochastic dynamic programming model (DP) using the hierarchic Markov technique (Kristensen 1988; Houben et al.) with Bayesian updating (Kristensen 1993). Although payoff levels are good indicators of overall decision quality, they do not provide good insight into the decision-making strategy that subjects (should) have applied, nor into the type of decision-making errors that are made. Some good decisions may result in bad outcomes, and vice versa, due to the uncertainty in the decision problem. For each project in the project files, the DP solution provides the optimal time of replacement and the losses from suboptimal replacement (Bellman). Simulation of an experimental session using the optimal decision strategy results in a score of 1,042,287 points for the treatments M1 and B1, and 1,040,761 points for the treatments M2 and B2. Consequently, deciding according to the theoretically optimal strategy yields a total score in the experiment of 2,083,048 points, which equals a payoff of $88.91. In describing the results, we shall refer to opportunity costs from suboptimal replacements as "losses." If replacement is done too early, the loss is defined as the difference in expected future profitability between the replaced project (at the time of replacement) and a new project (Bellman). If replacement is done too late, the loss equals the summation of differences in expected future profitability over the years after the optimal time of replacement, updated with the new production data in each year.

Results

The experiment consisted of eight separate experimental sessions involving a total of

Table 2. Mean Yield Losses (i.e., Optimal Minus Actual Decision Making), of the 48 Subjects in the MIS Group and 38 Subjects in the Baseline Group

		Loss (σ)	Loss (σ)	Wilcoxon Test			
	n	treatment	treatment	#−	#+	Z	*p*
MIS	48	55,050 (53,452)		20	28	−1.2923	
Baseline	38	51,784 (36,342)		21	17	−1.0079	0.3135

eighty-six Dutch pig farmers. The farmers were not randomly assigned to the treatment groups: forty-six of the forty-eight farmers in the MIS group and five of the thirty-eight farmers in the control group came from farms that participated in the survey study of Verstegen et al. (1995a). The only selection criterion for the other farmers in both treatment groups was a pragmatic one: that they should live near the agricultural education center where the experiment was conducted. In 1992, the farmers in the survey study were only slightly above the national average with respect to farm size and production results. However, 76% of them used MIS whereas the national average was 41% (Verstegen et al. 1995a). Differences in MIS experiences are not a likely source for bias in the experiment because most Dutch pig farmers used MIS in 1996. The advantage of the assignment procedure was that survey MIS estimates previously derived for these farmers could be compared to MIS estimates derived from the experiment.

The farmers in the experiment learned to use the computer program rapidly and were very concentrated on their decision making until the end of the experimental session. Payoff levels ranged between $9.09 and $88.48. If more than one worker from a survey farm participated in the experiment, only the one with the best performance was actually paid. The average score of the subjects was 71% of the optimal-strategy score derived from the DP solution.

Table 2 shows the mean losses (i.e., mean opportunity costs from suboptimal replacement) and standard deviations for the eighty-six subjects in the experiment. Because the losses tend not to be normally distributed (Kolmogorov-Smirnov goodness-of-fit test), they were analyzed with nonparametric tests. In the MIS group, twenty subjects encountered higher losses (i.e., lower rankings) in the second treatment with processed data than in the first treatment with raw data, whereas the other twenty-eight subjects in the MIS group reduced their losses. However, in the baseline group twenty-one out of thirty-eight subjects had higher losses in the second treatment. None of the differences in table 2 was found to be significant due to large variation in losses across subjects (Wilcoxon test). Some of the subjects clearly misunderstood the essence of the decision problem and repeatedly kept investment projects past their productive lifetime of ten years. As was emphasized in the instructions and indicated on the project cards on the computer screen, projects have zero yield after ten production years (while the yearly fixed costs remain). It appeared that the losses of keeping projects after ten production years largely dominated the losses of suboptimal replacement within the productive lifetime of ten years and were likely to disguise possible MIS effects. Therefore, subjects who clearly misunderstood the essence of the problem and did not correct themselves after they got feedback on the computer screen were excluded from the analysis. Further analysis was done with the sixty-three subjects who made fewer than five errors (one project kept for one year after ten years = one error). The losses caused by these errors were replaced by the average loss of the subject (apart from these errors).

Table 3 shows that mean values and standard deviations of losses in the baseline and MIS groups are drastically lowered by the exclusion of subjects who misunderstood the decision problem. In the first treatment, which was exactly the same for all subjects, 11% of the projects in both groups were replaced in the right production year. Losses from suboptimal replacement tended to be higher for subjects in the baseline group but the difference with the MIS group was not significant ($p = 0.13$ for the Mann-Whitney U-test). The

Table 3. Mean Yield Losses (i.e., Optimal Minus Actual Decision Making), of the 35 Selected Subjects in the MIS Group and 28 Selected Subjects in the Baseline Group

		Loss (σ)	Loss (σ)	Wilcoxon Test			
				#−	#+	Z	p
MIS	35	27,465 (11,111)	24,132 (12,010)	10	25	−2.2767	
Baseline	28	34,493 (16,495)	33,537 (19,778)	11	17	−0.9109	0.3624

second treatment differed between the MIS and baseline groups and resulted in significantly different mean losses ($p = 0.02$ with the Mann-Whitney U-test). The subjects in the MIS group replaced 15% of the projects correctly and reduced their losses by 3,333 points ($p = 0.02$ with the Wilcoxon test). Projects appeared to be better evaluated. Those with a relatively low production potential were replaced earlier, and those with a relatively high production potential were replaced later. Reduction of losses was higher with the project types that had one good and one bad property (LM and HF) than with the simpler project types that had either two good (HM) or two bad properties (LF). In the second treatment, the subjects in the baseline group replaced 13% of the projects correctly, but this did not significantly reduce their losses ($p = 0.36$ with the Wilcoxon test). The reduction of losses in the MIS group relative to the baseline group is 2,377 (= 3,333 − 956) points. However, this relative reduction is not significant ($p = 0.34$ for the Mann-Whitney U-test) due to the large variation in losses across subjects.

The purpose of this study was to learn if experimental economics methods could confirm the outcome of the survey study and hence could be used as an alternative approach for determining the profitability of MIS in sow farming. Therefore, individual MIS estimates derived from the experiment were compared with individual MIS estimates from the survey study. Comparisons could be made only if MIS estimates were available from both the experimental and survey studies, and if the same farm member participated in both studies. Of the thirty-five subjects selected in the MIS group, nineteen comparisons could be made. Unfortunately, no significant correlation was found between the two MIS estimates (Spearman correlation = −0.35; $p = 0.14$).

Discussion

Although the experimental study revealed an overall effect of MIS, as did the survey study of Verstegen et al. (1995a), problems with the experimental procedures complicated translation of the results to the natural situation. Analysis of the errors in the experiment showed that, in both the first and second treatments, subjects replaced 60% of the projects too early and 27% of the projects too late, whereas, in the natural situation, most farmers tend to replace sows too late (Dijkhuizen, Krabbenborg, and Huirne).

A refined experimental design, changing one parameter at a time, could have given more insight into the importance of differences between the laboratory and the natural environment. For this study, however, a specific group of farmers who already had participated in a survey study on the profitability of MIS was recruited, allowing a comparison between survey MIS estimates and experimental MIS estimates. Because of the small number of survey farmers, this procedure limited the number of parameters that could be varied in the experimental design. Experimental design features that should be varied in future research are (*a*) the level of communication between subjects; (*b*) the length of the training period; (*c*) the amount of emphasis on marginal yields of projects; and (*d*) the specific way in which the decision problem is framed.

Communication between subjects was prohibited to ensure that the amount of information available to the subjects was identical in each of the eight experimental sessions. In the natural situation, however, decisions grow out of a synthesis of experiences, aspirations, and information from colleagues and farm advisors (Nitsch).

Several training periods were included in the experiment to facilitate development of decision-making rules, but in the natural situation "training periods" cover almost a lifetime (Nitsch) and are strongly affected by communication and farm comparisons (Leeuwis). In the experiment, only feedback on earlier decisions through the production results of the projects could be used for learning.

Some of the subjects repeatedly kept investment projects past the productive lifetime of ten production years. The projects then had zero marginal returns but still had fixed costs of 3,450 points per period, meaning that the total scores of these subjects dropped drastically. In the natural situation, farmers are not likely to make such a mistake because the marginal yield of a sow is prominently visualized through her last litter size. Redesigning the project cards, placing more emphasis on marginal returns, may avoid some of the problems encountered in the experiment.

Less training would be required and misunderstandings could be avoided if the natural decision problem (Dickson, Senn, and Chervany) were used instead of the more abstract investment project selection problem. The reason is that farmers could apply their usual decision-making rules to the problem. However, framing the experimental task as sow replacement decisions would also mean that the amount of information available to the subjects would no longer be controlled. In order to gain the advantages of a less abstract experimental task and also control the subjects' information about the decision problem, an interesting option for further research may be to frame the decision as a replacement problem of uncommon livestock with different parameters, such as crocodiles. With that approach, it would be easier for subjects to grasp the essence of the decision problem but their usual decision rules could not be thoughtlessly applied.

Conclusion

An investment project selection problem was constructed to be an abstract experimental economics analogue of the sow replacement problem, and eighty-six pig farmers were used as subjects in the experiment. Subjects receiving MIS features improved their decision making between the first and second treatments, whereas subjects without MIS features did not. In nineteen within-farmer comparisons, no significant correlation was found between the individual MIS estimates derived from the experiment and those from a survey study (Verstegen et al. 1995a). Biases in both the experimental MIS estimates and the survey MIS estimates (due to exogenous changes on farms other than MIS use) are the most likely explanation for this outcome.

A refined experimental design, including redesigned project cards placing emphasis on marginal yields of projects, varying abstractness of the decision problem, varying levels of communication between subjects, and varying lengths of the training period, is suggested for further research. The first two aspects entail a better explanation and framing of the investment selection problem. The other two aspects involve communication and learning. The inclusion of (controlled) interaction between subjects in the experimental procedures would stimulate learning and parallel the natural situation, where farmers exchange information with colleagues and farm advisors.

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Appendix 1

Analogy between the Investment Project Selection Problem and the Natural Sow Replacement Problem

Investment Project Selection	Sow Replacement
Two decision alternatives: to keep or to replace a project	Two decision alternatives: to keep or to replace a sow
First one group of fifteen projects is evaluated (during 120 seconds). Afterwards, the same is done with a second group of fifteen projects. This procedure is repeated each experimental year.	Each week ten to fifteen sows are evaluated. After one production cycle the sows that were kept before are evaluated again.
A project that has been replaced will never again return in the portfolio of projects.	Once a sow has been replaced, the decision can never again be recalled.
Replacement decisions become effective at the end of an experimental year. Marked projects are then immediately replaced by a new project.	Sows that are removed from the herd are replaced by gilts to keep the herd size intact.
A project's production history provides imperfect information about its potential to have a certain yield per experimental year.	A sow's production history provides imperfect information about her potential to produce a certain amount of piglets per year.
Each experimental year, new information on the production potential of a project becomes available.	Each parity, new information on the production potential of a sow becomes available.
The production potential of a project is fixed and consists of two properties, namely (1) the yield per production week, and (2) the number of production weeks per experimental year.	The production potential of a sow is fixed and consists of two properties, namely (1) the number of piglets per litter, and (2) the number of litters per year.
The yield per production week is at its maximum level in the fourth year of production.	The litter size is at its maximum level in the fourth parity.
The maximum productive lifetime of a project in the experiment is ten experimental years.	The maximum productive lifetime of a sow is ten parities.

Appendix 2

Analogy between the Economics Experiment and the Natural Situation, Both "Without" and "With" MIS

Economics Experiment	Natural Situation
Without MIS (Treatments M1, B1, B2)	
Individual project cards show per year:	Individual sow cards show per parity:[a]
(1) starting and ending dates of the production period	(1) insemination dates
	(2) farrowing dates
(3) yield per production week	(3) litter sizes: no. of piglets born alive/dead
(4) number of production years	(4) number of parities
With MIS (Treatment M2)	
Project cards show per year:	Sow cards show per parity:
	(1) insemination dates
	(2) farrowing dates
(3) number of production weeks per year	(3) sow-specific farrowing index figures[b]
(4) yield per production week	(4) litter sizes: no. of piglets born alive/dead
(5) total yield per year[c]	(5) sow-specific number of piglets produced per year[c]
(6) number of production years of the project	(6) age of sow
Options to obtain:	Options to obtain:
(1) overviews of projects sorted on the number of production years or the average of total yields per year	(1) standard overviews of sows
	(2) user-defined overviews
	(3) user-defined analyses
	(4) working lists
	(5) attention lists
Average values per project on project cards and overviews	Average values per sow on sow cards and overviews

[a] Sow production cycle.
[b] Number of farrowings per year.
[c] (5) is the product of (3) and (4).