Technical Efficiency of dairy farms with and without sensors

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Summary

In the recent years the most common development that can be noticed is the development and increase of the use of sensors in dairy farming. With the use of sensors parameters and indicators of an individual dairy cow can be measured and help the farmer detect estrus, lameness, clinical mastitis, etc. Several sensors, such as the sensors to detect mastitis, are integrated on an automatic milking system (AMS). The use of sensors on a farm requires a different management, to improve cow management, and has a corresponding change in inputs and outputs. The main inputs which the use of sensors can possibly affect are labor costs, animal health costs and available capital.

Several reviews on sensors are published, but these reviews are limited to a specific type or specific application of a sensor and the main focus of these reviews is on the performance of these sensors. There are also some reviews on the feasibility, profitability or the Technical Efficiency (TE) of the milk robot or AMS in specific, while the economic value of sensors remains unclear. Since the use and development of sensors is increasing, an urge has grown for a clear analysis of the economic value of a sensor system. Therefore, the objective of this study is to investigate and compare the Technical Efficiency of dairy farms with and without sensors.

The data used in this research contains of two data sets. The first data set is collected through an online survey completed in 2013, by dairy farmers in the Netherland. It consisted of information of 512 farms on the sensors itself, of the farmer, the hours worked on the farm and the farm characterization. The farmers that completed the survey were clients of the Dutch accounting agency Accon AVM (Leeuwarden). The accounting agency provided the second data set, which consists of accounting data from 2012 of 217 out of the 512 dairy farms. In this data set accounting data such as number of cows, FTE on the farm, depreciation, revenues, variable costs and fixed costs is available. These two data sets are edited using the computer program SAS, resulting in a final data set of one time period (2012) which contains the output, total revenues, and five inputs, number of cows, total land used (ha), total labour costs, total variable costs and total capital costs of 212 farms with which a Data Envelopment Analysis (DEA) was conducted to calculate the TE. The DEA is conducted using the computer program DEAP and is input oriented and the variable return to scale is used.

This research shows no significant difference in TE between farms with and without sensors. The total capital costs on the other hand are significantly higher for the AMS farms, compared with the non-AMS and no sensor farms. The no sensor farms also have significantly lower total revenues than the AMS and non-AMS farms. When the farms using sensors are split up in groups with a specific type of sensor (udder, fertility and other), there also is no difference in TE score between these groups. Farmers spending more than 60 minutes per day on cow management have a lower TE score than farms spending less time on cow management.

Farms using sensors were expected to be more efficient than farms using no sensors, but this research shows no significant difference between these two. It can be assumed that the differences in inputs and output between the farms with and without sensors are too small to have any effect on the TE of these farms and have no economic effect. Another important issue in this research is the data used. The data contains information of farms which are clients of the accounting firm Accon AVM, these are not at random chosen farms all over the Netherlands and could possibly affect the results of this research. It could also be assumed that these farmers are already interested in how to improve their management, with which they can produce more efficient, since these farmers are voluntarily paying the accounting firm to get insight on their financial performance.

The overall conclusion is that there is no difference in TE between farms with and without sensors.

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1. Introduction

The process of research, creation and improvement of technology in the dairy sector has changed progressively due to the increase in production per cow, herd size, food expenses and economic value of the cow (Maltz, 2010). The increase in labor costs relative to capital costs is also a potential source for the development of technology and automated processes, to reduce labor and labor costs (de Koning, 2010; Svennersten-Sjaunja & Petterson, 2008). A need for more efficient labor use is due to the growing costs of labor in many dairy countries. Another need for more efficient labor or replacement of physical labor is to create a better social life for dairy farm families (de Koning, 2010). Despite the increased labor costs and the desire for an improved social life for the farmer, the production has to stay at an optimal level to be able to feed the current and future population (Delgado et al., 1999).

The most common development that can be noticed in the recent years is the development and increase of the use of sensors in dairy farming (Steeneveld & Hogeveen, 2014). The main purpose of the development of sensors is to improve cow management. Since the 1980's efforts have been made to develop sensors which measure parameters of an individual dairy cow (Rutten et al., 2013). With the use of sensors, it is able to measure behavioral, physiological and production indicators on individual cows (Espada & Vijverberg, 2002). Several sensors such as activity meters, pedometers and accelerometers have been developed to detect estrus and lameness (Firk et al., 2002; O'Connel et al., 2010; Holman et al., 2011; Pastell et al., 2009; Chapinal et al., 2010; Mikley et al., 2012). To help the farmer detect clinical mastitis electrical conductivity and color sensors are examples of sensors used to detect changes in the milk (Hovinen & Pyörälä, 2011; Espada & Vijverberg, 2002). These two sensors are an integrated part on an automatic milking systems (AMS) and are the most used sensors (Viguier, et al., 2009). There are also sensors to measure milk, fat and protein yield and milk components, with which the cow fertility and udder health can be measured (Katz et al., 2007; Friggens & Chagunda, 2005; Espada & Vijverberg, 2002). Other sensors are rumen pH sensors (Alzahal et al., 2007), sensor systems to measure the weight of cows (van der Tol & van der Kamp, 2010) and sensors to measure the rumination time (Bar & Solomon, 2010).

In dairy farming the main output variable, milk, is dependent on some input variables such as labor, number of dairy cows, number of pasture hectares, animal health-, roughage- and concentrates costs, etc. Optimal management of these inputs becomes more and more important, since slight changes in production efficiency can make the difference between profit and loss (van der Voort et al., 2014). The use of sensors on a farm requires a different management and has a corresponding change in inputs and outputs (Bewley, 2010).The main inputs which the use of sensors can possibly affect are labor, animal health costs and available capital. It is expected that the use of (a) sensor(s) will not only decrease the amount of physical labor required, but also the labor costs, animal health costs and the available capital (Bewley, 2010; Rutten et al., 2013; Steeneveld & Hogeveen, 2014). Due to the investment in sensor(s) the available capital is a very important input which will decrease and should not be left out when considering the use of sensors.

In the study of Rutten et al. (2013) 139 sensor systems were described and compared and it was concluded that the economic value of sensors remains unclear. The reviews on sensors published have been limited to a specific type of sensor or a specific application of a sensor, in specific the milk robot or the automatic milking system (Firk, et al., 2002; Norberg, 2005; Hogeveen et al., 2010; Gordon, 2011; Saint-Dizier & Chastant-Maillard, 2011). There are no scientific studies which are based on sensors in general and the economic insight of these sensors. For example; several studies on the feasibility, profitability and technical efficiency have been conducted for the AMS (Rossing et al., 1985; Bijl et al., 2007; Steeneveld et al., 2012), but none of such a study has been conducted for sensors in general. Steeneveld et al. (2012) compared Technical Efficiency (TE) between farms with an AMS and a conventional farm, and concluded that there is no observed significant difference between the technical efficiency of these farms.

Since the use and development of sensors is increasing, an urge has grown for a clear analysis of the economic value which a sensor system adds to the decision making of the farmer (Rutten et al., 2013). This lack of economic insight in sensors is a gap which currently exists in scientific research on sensors. There has not yet been a study which investigates the difference in technical efficiency between farms with and without sensors.

The objective of this study is to investigate and compare the Technical Efficiency of dairy farms with and without sensors.

2. Material and methods

Available data

The material in this study is data that originates from a Dutch accounting agency called Accon AVM (Leeuwarden). The clients of Accon AVM can be described as farmers which are interested in financial performance of their farm. These farmers can use this information to get an overview of their farm performance and to make better management decisions. The available data consists of two data sets. The first data set is collected through an online survey conducted in 2013 by dairy farmers in the Netherland, mostly in the north of the Netherlands. The main reason for conducting this survey is to study the investment in a sensor system on dairy farms (if it is useful or not) and also to study the usage of sensor systems in daily management. The survey link was sent to 1,672 Dutch dairy farmers through email. From these 1,672 farmers, 532 completed the survey. Because 20 of these farms indicated that they don't have dairy cows any more or because they indicated that they did not fill in the survey right, these were deleted from the data resulting in final dataset containing information of 512 dairy farms. From the 512 dairy farms, 310 farms declared that they don't have any sensors on their farms and 202 farms declared that they have at least one sensor system on their dairy farm. The information of this first data set is provided in a Microsoft Excel file and consists of information on the sensors itself (which senor(s) is (are) used on the farm, reason of investment, year of investment, etc.), information of the farmer, the hours worked on the farm and the farm characterization (e.g., number of cows, hectares, milk quota, etc.).

The second data set is also provided in Microsoft Excel and consists of accounting data from 2012 of 217 out of the 512 dairy farms. In this data set accounting data such as number of cows and FTE on the farm, depreciation (e.g., on buildings and machinery), revenues (e.g., from milk, land and other farm activities), variable costs (e.g., energy, water and feed costs) and fixed costs (e.g., costs for maintenance of machinery and buildings) is available.

Data editing

The data is available in Microsoft Excel and is prepared, edited and partly analyzed using the computer program SAS version 9.3. The computer program SAS is used to create the data which will be used in DEAP and also to do a GLM- and T-tests to characterize the farms and to detect differences between the farms. The two available data sets are sorted by farm number and merged together, resulting in a data set containing information on sensors, farm characteristics and accounting data from 217 dairy farms. The farms of which no accounting data was available were left out of the new data set. To make the file complete it was also analyzed for outliers using SAS, there were 3 outliers (hours worked on the farm >3,600, whereas the mean is around 100) and 2 farms of which some data was missing. These 5 farms were deleted from the new data set, resulting in a data set containing 212 farms: 89 with sensors and 123 with no sensors. The 'new' data set was used to define for each farm the output and the inputs and other variables such as the no. of cows, the information if the farm has (a) sensor(s), if the farm has an AMS, if the farmer has a successor, the time spent on cow management and the type of sensor which the farmer owns. The output variable total revenues contained the sum of 4 different revenues (milk revenues, turnover revenues, livestock revenues and remaining revenues). Total labor costs (paid labor, customer work and own labor), total variable costs (concentrates, roughage, wet by-product, milk powder, health care, breeding, fertilizer, energy, pesticides, manure removal, general costs and remaining costs) and the total capital costs (fuel, small equipment, insurance, rent, mechanization, expenses and depreciation for tools and territory) were defined as input variables. To calculate the total labor costs both Full Time Employee (FTE) and the number of hours worked per week on the farm were available. Because of this, the choice was made to do the DEA analysis with both and to compare the results. The total labour costs using FTE is calculated by: FTE*40*52*15.95; and the total labour costs using hour is calculated by: hours*52*15.95. (40 h per week, 52 weeks and an hour loan at the rate of 15.95 (CBS, 2012).

After merging, checking and adjusting the data several GLM and T-tests were done with the data set using SAS. These tests were done to calculate and compare the averages and differences between farms with and without sensors. The choice has been made to splits the group of sensors in farms with an AMS and non AMS farms, because of the difference in costs between investing in an AMS and investing in a conventional milking system (CMS) with sensors (non-AMS farms). After these tests the farms with sensors are also split up into groups with specific type of sensor farms to create an even more in depth insight in the farms using sensors. These groups with specific type of sensors are farms with udder sensors, fertility sensors and other sensors (see table 1).

Table 1 Groups of specific type of sensors

Sensor group	Included sensors	Number of farms
Udder	Milk colour Somatic cell count Electrical conductivity LDH (lactate Dehydrogenase)	65
Non Udder	-	24
Fertility	Activity- /pedometer young cattle Activity-/ pedometer old cattle Body temperature Progesterone	57
Non Fertility	-	32
Other	Weight Rumination Fat/protein milk Rumen acidity (PH rumen) Milk temperature Urea BHB (beta-hydroxybutyric acid) Other	33
Non-other	-	56

Data analysis

To calculate the Technical Efficiency (TE) a Data Envelopment Analysis (DEA) was performed using the final data set created in SAS and the computer program Data Envelopment Analysis Program (DEAP). The computer program DEAP Version 2.1 is used to construct Data Envelopment Analysis frontiers for the calculation of cost and technical efficiencies (Coelli, 1996). Date Envelopment Analysis (DEA) is a nonparametric method with which the relative efficiency or performance of Decision-Making Units (DMUs) can be evaluated. DEA involves measuring and evaluating the performance and analyses multiple-input and multiple-output production technologies. To determine which DMUs are producing at efficient levels DEA compares multiple levels of input and outputs for a given DMU with all other DMUs in the data set (Picazo-Tadeo et al., 2011).

The final data set contains data from one time period (2012) from 212 firms; 89 firms with sensors and 123 firms without sensors. The total revenues are used as output and the five inputs are number of cows, total land used (ha), total labour costs, total variable costs and total capital costs (see table 2). The DEA is input oriented, since the output of a dairy farm is constant most of the times, and the variable return to scale is used.

The TE for farms with and without sensors was calculated, followed by the TE for the farms with sensors only. Calculating the TE with sensors only was done to calculate the average and differences on the TE score for the different type of sensors (udder, fertility and other), the time spent on cow management per day and if the farm has a successor or not. These averages and the average and difference of the farms with and without sensors were calculated by transferring the final results of the DEA to the original data in SAS with which the averages and differences on the TE are calculated.

3. Results

An overview of the output and the inputs of the 89 farms with sensors (53 farms with an AMS and 36 non-AMS farms) and 123 farms without sensors are shown in table 2. In the table there is also an overview of the included farm accounting data out of which a certain input or the output consists. These inputs and output are expressed in totals per cow, to allow comparisons across farms. The table shows no significant difference between these farms for the total land use, total labor (FTE), total labor (hours/week) and the total variable costs. The total number of cows on the other hand shows to be significantly higher for the non-AMS farms (127) compared with the AMS (105) and no sensor farms (96). The total capital costs are significantly higher for the AMS farms (1,337.99), compared with the non-AMS (965.31) and no sensor farms (9.34.43). Another difference that is shown in table 2 is the significant difference in total revenues between farms with no sensor and AMS and Non-AMS farms. The no sensor farms have a significantly lower (3,491.00) total revenue than the AMS (3,648.83) and non-AMS farms (3,676.83). Although there is no significance difference in total labor for both FTE and hours per week, the own labor on the other hand shows significant difference. The own labor (FTE) of Non-AMS farms (448.95) is significantly lower than the own labor (FTE) of the no sensor farms (571.74). The own labor (hours/week) of farms with an AMS (725.52) is also significantly lower from the own labor (hours/week) from the no sensor farms (887.30).

Table 2 Description of the average inputs and output variables used for the Data Envelopment Analysis (DEA) and the average values for farms with an Automatic Milking System (AMS), non-Automatic Milking system and no sensors in 2012.

Variable	Included farm data	Sensors (n=89)		No sensors (n=123)
		AMS (n=53)	Non-AMS (n=36)	
No. of Cows	Total number of cows	105[a]	127[b]	96[a]
Land in use (ha/cow)	Total land use	1.12[a]	1.22[a]	1.19[a]
Labor costs (€/cow)	Paid labor	66.30[ab]	85.04[a]	34.65[b]
	Customer work	291.82[a]	309.51[a]	263.71[a]
	Own labor[1] (FTE)	513.34[ab]	448.95[a]	571.74[b]
	Own labor[2] (Hours/week)	725.52[a]	740.98[ab]	887.30[b]
	Total labor (FTE)	871.46[a]	843.51[a]	870.09[a]
	Total labor (Hours/week)	1,083.64[a]	1,135.54[a]	1,185.65[a]
Variable costs (€/cow)	Concentrates	719.38[a]	682.26[ab]	655.54[b]
	Roughage	84.71[a]	67.50[a]	105.21[a]
	Wet by-product	57.47[a]	110.89[b]	60.38[a]
	Milk powder	23.55[a]	26.89[a]	21.24[a]
	Health care	103.39[a]	98.63[a]	99.93[a]
	Breeding	75.40[a]	72.07[a]	78.76[a]
	Fertilizer	11,212.34[a]	14,718.45[b]	1,0985.18[a]
	Energy	125.43[b]	84.33[a]	99.84[a]
	Pesticides	41.52[a]	37.49[a]	35.43[a]
	Manure removal	6.02[a]	7.22[a]	8.04[a]
	General costs	202.50[a]	193.57[a]	191.11[a]
	Remaining costs	112.43[a]	130.79[a]	108.70[a]
	Total variable costs	1,689.46[a]	1,660.38[a]	1,604.35[a]
Capital Costs (€/cow)	Fuel costs	111.74[a]	90.65[ab]	83.14[b]
	Small equipment costs	158.23[a]	141.07[a]	138.02[a]
	Insurance costs	9.99[b]	3.80[a]	5.97[a]
	Rent costs	7.64[a]	2.37[a]	9.43[a]
	Mechanization	2.00[a]	0.98[a]	0.25[a]
	Expenses for tools	381.00[b]	252.71[a]	259.11[a]
	Depreciation on tools	258.01[b]	156.60[a]	167.86[a]
	Expenses for territory	120.18[a]	93.95[a]	97.71[a]
	Depreciation on territory	289.19[a]	223.18[ab]	172.93[b]
	Total capital costs	1,337.99[b]	965.31[a]	934.43[a]
Revenues (€/cow)	Milk revenues	3,240.28[a]	3,262.23[a]	3,072.51[b]
	Turnover revenues	262.88[a]	262.77[a]	268.86[a]
	Livestock revenues	83.01[a]	89.47[a]	90.19[a]
	Remaining revenues	62.67[a]	62.36[a]	59.44[a]
	Total revenues	3,648.83[a]	3,676.83[a]	3,491.00[b]

a-b: averages in one row sharing the same superscript are not significantly different from each other; averages that have no superscript in common are significantly different from each other ($P<0.05$)

[1] Own labor (Full Time Employee) was calculated by multiplying the full-time equivalent by 52 weeks, by 40h and by €15.95 (CBS, 2012)

[2] Own labor (Hours/week) was calculated by multiplying the number of hours worked on the farm per week by 52 weeks and by €15.95 (CBS,2012)

The average characteristics and differences between the farms with an AMS, non-AMS and no sensor are shown in table 3. The milk quota of the non-AMS farms (1,076,698.58) is significantly higher compared to the AMS (892,346.18) and no sensor farms (761,230.86). There is also a significant difference in the milk produced between the non-AMS and no sensor farms, where the milk produced by the non-AMS (1,063,356.18) is significantly higher than the milk produced by the no sensor farms (758,484.86). The cow/hour shows no significant difference between the farms, but the cow/FTE and the FTE/cow do show significant difference. The cow/FTE for non-AMS farms (85.60) is significantly higher than the cow/FTE of the no sensor farms (65.77). The FTE/cow is significantly higher for the no sensor farms (0.017) than the non-AMS farms (0.014). The hour/cow is also significantly higher for the no sensor farms (1.07) when compared with the AMS farms (0.88). The milk/cow and the milk/FTE are both significantly lower for the no sensor farms (7,889.40-521,273.53) when compared with the AMS (8,390.62-633,609.45) and non-AMS farms (8,314.61-711,035.05). The milk/hour also shows a significant difference, but in this case the milk/hour for no sensors (8,830.87) is only significantly lower than the AMS farms (10,999.53).

Table 3 Average characteristics of farms with an Automatic Milking System (AMS), non-AMS and farms without sensors in 2012

	Sensors		No Sensors
	AMS (n=53)	**Non-AMS (n=36)**	**(n=123)**
Age of the farmer (years)	47.72^{a}	45.28^{a}	46.44^{a}
No. of dairy cows	105.07^{a}	126.79^{b}	95.69^{a}
Total land use per cow (ha)	1.12^{a}	1.22^{a}	1.19^{a}
Milk quota (kg)	$892,346.18^{a}$	$1,076,698.58^{b}$	$761,230.86^{a}$
Milk produced (kg)	$884,553.26^{ab}$	$1,063,356.18^{a}$	$758,484.86^{b}$
Fat(%)	4.40^{a}	4.45^{a}	4.42^{a}
Protein (%)	3.48^{b}	3.56^{a}	3.55^{a}
Cow/FTE[1]	75.10^{ab}	85.60^{a}	65.77^{b}
Cow/hour[2]	1.30^{a}	1.27^{a}	1.11^{a}
FTE/Cow	0.015^{ab}	0.014^{a}	0.017^{b}
Hour/Cow	0.88^{a}	0.89^{ab}	1.07^{b}
Milk/Cow (kg)	$8,390.62^{a}$	$8,314.61^{a}$	$7,889.40^{b}$
Milk/FTE (kg)	$633,609.45^{a}$	$711,035.05^{a}$	$521,273.53^{b}$
Milk/Hour (kg)	$10,999.53^{a}$	$10,531.87^{ab}$	$8,830.87^{b}$

[1] FTE= Full Time Employee

[2]Total number of hours worked per week on the farm

a-b: averages in one row sharing the same superscript are not significantly different from each other (P<0.05)

The results of the DEA analysis in which FTE was used to calculate the total labor costs are shown in table 4. This table shows no significant difference between the TE of farms with an AMS (0.9061), non-AMS (0.9106) and no sensors (0.9109). The table also shows the minimum and maximum value and the 95% Confidence Interval (CI) of the TE.

Table 4 Average Technical Efficiency (TE) calculated with FTE for farms with an Automatic Milking System (AMS), non-AMS and without sensors.

	TE	**Min-Max**	**95% CI**
AMS	0.9061^{a}	0.7150-1	0.8874-0.9248
Non-AMS	0.9106^{a}	0.7130-1	0.8833-0.9379
No sensor	0.9109^{a}	0.7140-1	0.8985-0.9233

a-b: averages in one column sharing the same superscript are not significantly different from each other (P<0.05)

The same results as shown in table 4 are shown in table 5, but in this case the numbers of hours worked on the farm per week were used to calculate the total labor costs. In these tables the TE is also not significantly different from each other, whereas the TE for AMS farms is 0.9036, for non-AMS farms is 0.9144 and for no sensor farms is 0.9037.

Table 5 Average Technical Efficiency calculated with hours worked on the farm per week, for farms with Automatic Milking System (AMS), non-AMS and without sensors.

	TE	Min-Max	95% CI
AMS	0.9036[a]	0.7130-1	0.8830-0.9242
Non-AMS	0.9144[a]	0.7820-1	0.8930-0.9358
No sensor	0.9037[a]	0.7140-1	0.8903-0.9170

a-b: averages in one column sharing the same superscript are not significantly different from each other ($P<0.05$)

When the TE is calculated for the farms with sensors only, the average TE scores are 0.9369 and 0.935 calculated with FTE and hour (see table 6).

Table 6 Results of the Data Envelopment Analysis for farms with sensors only, showing the average Technical Efficiency (TE) calculated with Full Time Employee (FTE) and hours per week worked on the farm.

	TE	Min-Max	95% CI
FTE	0.9369[a]	0.7230-1	0.9231-0.9507
Hour	0.9350[a]	0.7230-1	0.9211-0.9489

a-b: averages in one column sharing the same superscript are not significantly different from each other ($P<0.05$)

From the 89 farms using sensors the average TE for three sensor groups, udder, fertility and other, were calculated with both, FTE and hours used to calculate the total labor costs per cow. Both result in no significance difference in TE between non-udder and udder sensor, non-fertility and fertility sensor and non-other and other sensor using farms.

Table 7a Results of the Data Envelopment Analysis, showing the average Technical Efficiency (TE) calculated with Full Time Employee for the individual sensor groups

	TE	Min-max	95% CI
Non udder sensors (n=24)	0.9557[a]	0.8260-1	0.9328-0.9787
Udder sensors (n=65)	0.9300[a]	0.7230-1	0.9131-0.9468
Non fertility sensors (n=32)	0.9355[a]	0.8100-1	0.9114-0.9596
Fertility sensors (n=57)	0.9377[a]	0.7230-1	0.9204-0.9550
Non other sensors (n=56)	0.9378[a]	0.7230-1	0.9194-0.9563
Other sensors (n=33)	0.9353[a]	0.8260-1	0.9140-0.9567

a-b: averages in one column sharing the same superscript are not significantly different from each other ($P<0.05$)

Table 7b Results of the Data Envelopment Analysis , showing the average Technical Efficiency (TE) calculated with hours per week worked on the farm for the individual sensor groups

	TE	Min-max	95% CI
Non udder sensors (n=24)	0.9494[a]	0.8260-1	0.9250-0.9738
Udder sensors (n=65)	0.9297[a]	0.7230-1	0.9128-0.9467
Non fertility sensors (n=32)	0.9370[a]	0.8010-1	0.9133-0.9607
Fertility sensors (n=57)	0.9339[a]	0.7230-1	0.9162-0.9516

Non other sensors (n=56)	0.9355^{a}	0.7230-1	0.9169-0.9541
Other sensors (n=33)	0.9342^{a}	0.8200-1	0.9126-0.9558

a-b: averages in one column sharing the same superscript are not significantly different from each other (P<0.05)

The farms which have cow management from 0-10 minutes per day have a TE of 1, this means that these farm are efficient (see table 8a and 8b). The TE, both calculated with FTE and hours per week, of the four groups of time invested in management show significant difference between several groups. For both the calculations with FTE and hours per week worked on the farm the TE of the farms with cow management more than 60 minutes per day have a significant lower score when compared with the other farms (0-10min/day, 10-30 min/day and 30-60 min/day).

Table 8a Average Technical Efficiency (TE) scores for four groups of the time spent on cow management calculated with Full Time Employee.

Time spent on cow management	n	TE	Min-Max	95% CI
0-10 min/day	3	1^{a}	1-1	-
10-30 min/day	36	0.9564^{a}	0.8260-1	0.9388-0.9740
30-60 min/day	39	0.9373^{a}	0.8200-1	0.9180-0.9566
>60 min/day	11	0.8545^{b}	0.7230-1	0.8086-0.9003

a-b: averages in one column sharing the same superscript are not significantly different from each other (P<0.05)

Table 8b Average Technical Efficiency (TE) scores for four groups of the time spent on cow management calculated with hour per week on farm

Time spent on cow management	n	TE	Min-Max	95% CI
0-10 min/day	3	1^{a}	1-1	-
10-30 min/day	36	0.9544^{a}	0.8250-1	0.9367-0.9721
30-60 min/day	39	0.9348^{a}	0.8200-1	0.9150-0.9547
>60 min/day	11	0.8546^{b}	0.7230-1	0.8082-0.9011

a-b: averages in one column sharing the same superscript are not significantly different from each other (P<0.05)

When looking at the information we have on the farm about a successor, the average TE shows no significance differences between a successor, no successor and not knowing yet if there is a successor or not for both situations (FTE and hours per weeks).

Table 9a Technical Efficiency (TE) scores for three successor groups calculated with Full Time Employee

Successor	n	TE	Min-Max	95% CI
yes	31	0.9298^{a}	0.7970-1	0.9044-0.9553
no	10	0.9275^{a}	0.7320-1	0.8629-0.9921
don't know yet	48	0.9434^{a}	0.8100-1	0.9268-0.9601

a-b: averages in one column sharing the same superscript are not significantly different from each other P<0.05)

Table 9b Technical Efficiency (TE) scores for three successor groups calculated with hour per week on farm

Successor	n	TE	Min-Max	95% CI
yes	31	0.9300^{a}	0.7970-1	0.9043-0.9557
no	10	0.9230^{a}	0.7230-1	0.8602-0.9858
don't know yet	48	0.9408^{a}	0.8010-1	0.9237-0.9579

a-b: averages in one column sharing the same superscript are not significantly different from each other (P<0.05)

4. Discussion

No significant differences

Defined inputs

It was expected that the main inputs labor hours, labor costs, animal health costs and capital costs would be affected by the use of sensors. The amount of physical labor required, labor costs and animal health costs were expected to decrease with the use of (a) sensor(s) (Bewley, 2010; Rutten et al., 2013; Steeneveld & Hogeveen, 2014). Due to the investment in sensor(s) the available capital is also expected to decrease when considering the use of sensors, and the capital costs are thus expected to increase.
When looking at the results of this research we can see that in all of these cases there is only a significant difference in the total capital costs per cow. The total capital costs are significantly higher for the AMS farms (1,337.99), compared with the non-AMS (965.31) and no sensor farms (9.34.43). This justifies the expectation that investing in an AMS has a strong influence on the available capital.

The total labor costs and the health costs on the other hand, show no significant difference when the averages are calculated with both FTE and hours per week. Since both these variables were available, the choice was made to use both to calculate the total labor costs. The FTE is most of the time a not so accurate, rough guessed number which the farmers use for their accounting information, while the numbers of hours worked on the farm are a result of the survey which was completed by the farmers. Although the costs for own labor calculated with both FTE and Hour shows significant different between the three defined types of farms (see table 2), this significant difference has no effect on the total labor costs. The own labor is probably not used efficiently or maybe the farmer invests his own labor hours in other activities of the farm (e.g. fertilizing, grass growth, etc.). Overall the effects of the difference in own labor are too small and do not have an effect on the economic performance of the farm.

Comparing Technical Efficiency sensor and no sensor

A DEA between farms using sensors (farms with an AMS and non-AMS farms together) and no sensors was also conducted to calculate the TE with FTE and hours per week worked on the farm (results not shown). These results also show no significant difference between farms using sensors (0.9079; 0.9080) and farms using no sensors (0.9109; 0.9037).

Farms using sensors were expected to be more efficient than farms using no sensors. In this research there is no significant difference in the TE score between farms with and without sensors (see table 4&5), when using the revenues as an output and no. of dairy cows, total land use, total labor costs, total capital costs and the total variable costs as inputs. Two out of these five inputs, no. of cows and the total capital costs, show significant difference in between the three different farm groups. These differences are too small to have any effect on the TE of these farms and have no economic effect on the farms.

When considering the efficient use of the sensors, it could be that the farmers using sensors are not familiar with working efficient with the sensors yet or don't even use the output of the sensors. Furthermore, most of the investments in sensors are made in 2011; which could be a possible reason why farmers are not used to working with the sensors and the output yet. It could also be that the time period (2011-2012) is a too short time period to see any effects of the use of sensors on a farm.

Another explanation for the results of this research, no significant difference between farms with and without sensors, could be the data used in this research. The data used in this research is data from 212 farms that are voluntarily clients of the accounting agency Accon AVM and which also voluntarily completed the survey. The clients of Accon AVM can be described as farmers which are voluntarily interested in the financial performance of their farm, with which they can make better management decisions. Since the farmers voluntarily completed the survey, it can be assumed that these farms are already interested in the use of sensors. It can also be assumed that these farmers, even the farms with no sensors, are already interested in how to improve their management with which they can produce more efficient since these farmers are voluntarily paying the accounting firm to get insight on their financial performance. It could be that the no sensor farms in this research already use the information they get from the accounting agency to improve their management and produce more efficient than random farms in the Netherlands with no sensors. Since the farms used in this research are not at random chosen farms all over the Netherlands, this could possibly affect the results of this research

Comparing Technical Efficiency different type of sensors
The TE between the different types of sensors also shows no significant difference between the different sensor groups (see table 7a and 7b). For the group of udder sensors, one would expect farms using these types of sensors to be more efficient in health- and labor costs, since these help the farmer to detect mastitis. Not only could the use of udder sensors help reduce antibiotic use, it could also reduce the amount of discarded milk resulting in less milk withdrawal. The farmer will also be able to decrease the amount of physical labor spent on observing, examining and treating the cow (Steeneveld, 2010).

Farms using fertility sensors were expected to be more efficient in labor costs. With the use of fertility sensors the farmer can get information of which cows for example are more active than usual. The farmer can use his labor in a more efficient way, since he does not has to walk through the farm and observe the cows himself (Rutten, et al., 2013b). Overall the effect of health and labor of these sensors is too small on the economic situations of these farms and thus has no influence on the TE score.

The other sensors also show no significant difference in TE. The output of the use of sensors in general could be used to support health management of the cows (Rutten, et al., 2013). The sensors could alert the farmer on the moment that there is something wrong with his cows. For example the rumination, fat content of the milk and the rumen acidity could be indicators to suspect subclinical rumen acidosis (Alzahal, et al., 2007). Another example is the use of the beta-hydroxybutyric acid (BHB) and fat/protein content to detect ketosis (Duffield, et al., 1997; LeBLanc, 2010). The use of these sensors could not only decrease the health costs, but also the labor costs (Bewley, 2010; Rutten et al., 2013; Steeneveld & Hogeveen, 2014), since the farmer does not have to make measurements and observations himself. The number of discarded cows and milk will also decrease. These reductions in costs and losses actually do not have that big an effect on the TE of the farms using other sensors.

Comparing Technical Efficiency Management
The farms with 0-10 minutes of management per day all have a TE score of 1, which means that these farms are all efficient. This TE score is actually the score of only 3 out of 89 farms.

The TE scores for the groups of time spent on management is significantly higher for the farmers with less than 60 min of time spent on cow management compared with the farmers with more than 60 minutes spent on cow management (see table 8a and 8b).

The expectation that if a farmer spends more time on cow management the TE would be higher is not proven with these results. The farms that spent more than 60 minutes per day on cow management (>60 min/day) could be less efficient because they spent too much time on the cow management, increasing their labor costs. Another reason why this could be is because of the amount of time spent on management, these farmers might detect and treat several diseases or illnesses earlier. This will not only increase the health costs for medicine and eventually veterinarians, but also the labor cost for treating the cows. It could also be that these farmers start treating the cows preventive, which also increases the health costs.

Comparing Technical Efficiency successor

If the farmer knows if there is a successor or not, or if he does not know yet, the TE score is also not significantly different. Farmers do not work more or less efficiently or invest more in their farms if they know if there is a successor or not, whereas one would expect farmers that know if they have a successor to be more efficient and that he would want to leave the farm in the best efficient situation for his successor.

Future research

As mentioned earlier in the discussion, the farms used in this research are not at random chosen farms all over the Netherlands, this could possibly affect the results of this research. In future research it is a recommendation to use data of at random chosen farms all over the Netherlands and not just farms that are already clients of a certain accounting agency.

Improving the efficiency of farms through the use of sensors, the adaptation and application of the use of sensors and the output of these sensors is very important. A recommendation is to support farmers on how to use the sensors and the output of these sensors. In future research one should take the year of investing in a sensor into account and also the degree to which a farmer is capable of using the output of the sensors to do the cow management (skills of the farmer).

In future research, other effects of the use of sensors, next to the economic ones which are used in this research should also be taken into account. That research should be based on the effect of sensors on the technical indicators (disease incidence, number of discarded cows, number of discarded milk, first calving age, Somatic Cell Count, etc.). It could be assumed that the use of sensors have the most effect or impact on this group of indicators.

5. Conclusions

The conclusions of this research are:

- Dairy farms using sensors do not produce more efficiently than farms without sensors. The Technical Efficiency between farms with and without sensors shows no significant difference, when the total revenues are used as output and the number of cows, total land used (ha), total labour costs, total variable costs and total capital costs are used as inputs.

- When considering the output and inputs on their own, the total capital costs are significantly higher for farms using an AMS compared to non-AMS farms and farms without sensors. The total labor costs do not differ significantly from each other between the three types of farms and the total revenues are significantly lower for the farms with no sensors than for the farms with sensors.

- Farms using udder-, fertility- or other sensors do not differ significantly in Technical Efficiency scores from each other.

- Farms with sensors, spending more than 60 minutes on cow management have a significantly lower Technical Efficiency score than farms spending less than 60 minutes on cow management.

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