Repair and Maintenance Costs for Agricultural Machines

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ABSTRACT

The paper presents an approach for deriving repair and maintenance factors intended to indicate the accumulated repair and maintenance costs for agricultural machines. In a two-stage approach, an annual repair and maintenance cost function is estimated and afterwards aggregated for the machine's estimated service life. Based on cross-sectional data, the approach is applied for tractors, ploughs, mowers and self-loading trailers in Switzerland, covering a wide range of agricultural mechanisation.

The results of our study show that, in line with the literature, an additional year in service increases annual repair and maintenance costs for all machine types under consideration. Furthermore, annual utilisation strongly influences repair and maintenance costs, a fact which, to our knowledge, has so far not been taken account of in the literature. For all analysed machines, increasing annual utilisation leads to a disproportionately low increase in repair and maintenance costs, revealing the existence of an economy-of-scale effect. Assuming that the machine's estimated service life (also called estimated useful life) is completely exploited, the accumulated repair and maintenance costs depend strongly on the machine's annual utilisation. Accordingly, in order to minimise accumulated repair and maintenance costs, high annual utilisation coupled with a short length of service life is beneficial.

KEYWORDS: Repair costs; maintenance; agricultural machines; Switzerland

JEL codes: M11, Q12

1. Introduction

Machinery is an important cost factor in agriculture. Looking at wheat production in France, Germany and Canada, for instance, machinery costs account for 20 to 30% of total costs (Agri Benchmark 2009, p. 83). Accurate information on machinery costs is therefore an essential input for farm managers.

Machinery costs consist of several sub-cost items such as depreciation, interest rate, insurance, housing, fuel costs, and repair and maintenance costs. All of these sub-cost items are straightforward to calculate except for depreciation and repair and maintenance costs. As regards depreciation, two recent analyses compare different functional forms (Wu and Perry 2004, Wilson 2010). Dumler et al. (2003) as well as Wilson and Tolley (2004) apply several depreciation methods in order to compare their accuracies with prices of second-hand tractors from auction results, dealer or trade advertisements. Based on an estimated depreciation function, Wilson and Davis (1998) present an approach for calculating hourly costs of depreciation and interest charges for tractors.

By contrast, analyses of repair and maintenance costs have been few in number over the last 15 years. As pointed out by Stiens & Windhüffel (1990, p. 148), repair data is the key issue in machinery costs, representing a substantial pitfall. An important reason for this is that repair and maintenance costs tend to increase with machine age (Rotz 1987, p. 4). Farm-management literature focuses on the cumulative or accumulated repair and maintenance costs for the machine's estimated service life (also called estimated useful life or wear-out life). Typically, costs are represented as simplified factors indicating total accumulated repair and maintenance costs, formulated as a fraction of the machines' list price. These 'easy-to-apply' figures are provided to farmers in many countries for a broad variety of agricultural devices (e.g. ASAE 2003a and 2003b, Whitehead & Archer 2010, Gazzarin & Albisser 2010). As an example, a repair and maintenance factor of 0.5 for a tractor with a list price of Swiss Francs[2] (CHF) 100,000 indicates that repair and maintenance costs of CHF 50,000 accrue during the machine's estimated service life, i.e. 10,000 hours for tractors. Dividing the accumulated repair and maintenance costs by the estimated service life of the machine yields the average repair and maintenance costs per work unit (i.e. per hour for tractors).

In order to specify the repair and maintenance factor, a regression analysis explaining the accumulated repair and maintenance costs as a function of accumulated work units is typically performed (e.g. Ward et al. 1985, Morris 1988, Wendel 1989, Bruhn 2000, Khoub bakht et al. 2008). Introducing the estimated service life as accumulated work units in the estimated function yields the repair and maintenance factor.

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[2] At mid-January 2012 one Swiss Franc (CHF1) was worth approximately US$1.07, £0.70 or €0.83

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Although widely applied, this approach suffers from two limitations. Firstly, only one independent variable is used, which reduces the explanatory power. As an important reason for this, a couple of analyses compare several functional forms, including quadratic form (Morris 1988, Bruhn 2000). Secondly, data requirements are substantial, with accumulated repair and maintenance costs as well as accumulated work units being necessary for each machine. To follow the trend of costs for each machine, the accumulated repair and maintenance costs for each service interval, say every 1,000 hours for tractors, is required. Bearing in mind that agricultural machinery can easily be used for 15 years or more, detailed records kept by the farm manager over decades are essential.

Morris (1988, p. 195f) also applies an alternative approach in his analysis. Instead of directly estimating an accumulated repair-and-maintenance-costs function, he tackles the problem in two steps. Firstly, the repair-and-maintenance-costs function per work unit is estimated by means of a regression analysis. Secondly, the integration of the cost function over work units approximates the accumulated repair and maintenance costs.

Similarly to Morris (1988), this paper suggests a two-stage approach allowing the introduction of several independent variables, particularly age and annual utilisation. Based on cross-sectional rather than accumulated data for repair and maintenance costs, the demonstrated approach substantially reduces data requirements. Using data from a recent survey, the approach is applied for four types of agricultural machines in Switzerland covering a wide range of agricultural mechanisation: tractors, ploughs, mowers and self-loading trailers (also known as self-loading forage wagons).

The paper is organised as follows: the data used are briefly described in the second section. Section three focuses on the suggested approach covering the estimation procedure, as well as the necessary aggregation. The results are reported in section four. Sections five and six are devoted to discussion and conclusions, respectively.

2. Data

In 2008, Albisser et al. (2009) conducted a postal survey on machinery costs in Switzerland. Out of the 2,000 randomly selected farms, 351 or 18% took part. Farm managers were asked to give detailed information on 14 selected machinery types frequently used in Swiss agriculture.

For each machine, farmers were asked to indicate some type-specific attributes, such as engine power for tractors or number of ploughshares for ploughs. In addition, the age of the machines and their annual utilisation over the last three years were recorded. To keep the effort required in responding to an acceptable level, the accumulated repair and maintenance costs were not included in the questionnaire. Instead, farm managers were asked to indicate their annual repair costs, including service agents' bills for the last three years. In addition, the material expenses for the last three years for repairs executed by farm employees are also taken into account[3]. Unfortunately, farm-employee labour input for on-farm repairs is not recorded in the survey. This leads to an underestimation of repair costs, and must be borne in mind when interpreting results. To summarise, average annual repair costs are derived from service agents' bills and material expenses on-farm.

For maintenance activities, farm managers were questioned about annual material costs and farm-employee labour input. The latter is calculated at the rate of CHF 28 per hour, the standard hourly agricultural wage in Switzerland (Gazzarin & Albisser, 2010). Repair and maintenance costs are then added together. As a further step, repair and maintenance costs are divided by the machine type's list price, which reflects machine size (ASAE 2003b, p. 370). The list prices from the most recent machinery cost report (Gazzarin & Albisser, 2010) are applied, taking account of the specific type and size of machine. The resulting annual repair and maintenance costs expressed as a fraction of the machine's list price can also be interpreted as an annual repair and maintenance factor.

For our analysis, we concentrated on four types of machines: tractors, ploughs, mowers and self-loading trailers. All of these are of interest, either due to their mechanical complexity (tractors, mowers, self-loading trailers) or the substantial wear they undergo (ploughs), as well as their importance for Swiss agriculture. Furthermore, although machines with data gaps for age or annual utilisation are excluded from the analysis, a sufficient number of observations are available for these four machine types[4]. In total, we have 1,083 observations at our disposal. Some key figures for all four machine types are reported in Table 1.

The bulk of the 1,083 available machines – 655 – are tractors. On average, a tractor is utilised 272 hours a year. The average age of the machinery in the sample is 20 years. Assuming that the observed annual utilisation is representative of the entire lifespan, the length of service can be calculated. Given an estimated service life of 10,000 hours for tractors, the length of service is 37 years (= 10,000 h/272 h per year). The lengths of service for ploughs, mowers and self-loading trailers are 47, 23 and 42 years, respectively. It is therefore obvious that machine utilisation in Switzerland is fairly low, and it is doubtful that all machines attain their estimated service lives.

As for annual repair and maintenance costs, these vary between 0.012 and 0.036 of the machine's list price. Expressed per work unit, repair and maintenance costs account for CHF 4.56 (self-loading trailers) to CHF 34.45 (ploughs).

3. Method

Regression Analysis

In order to explain annual repair and maintenance costs as a dependent variable, we carry out a regression analysis leading to a cost function. Because the

[3] Although carrying out repairs requires specific training, we cannot rule out the possibility of such operations being performed on-farm.

[4] Data gaps for machine-type-specific data such as wide-base tyres (tractors) or number of knives (self-loading trailers) are treated differently. For continuous variables, we insert the mean values of the sample. For binary variables, the base case (normally without additional equipment) is applied.

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Table 1: Key figures for four machine types

	Tractors	Ploughs	Mowers	Self-Loading Trailers
Number of observations	655	127	90	211
Work unit (WU)	hour	hectare	hectare	cartload
Annual utilisation in WUs[1]	272 h	21 ha	52 ha	130 cartloads
Age, years in service	20	16	10	19
Estimated service life in WUs[2]	10,000 h	1,000 ha	1,200 ha	5,500 cartloads
List price in CHF[2]	72,786	20,721	14,038	55,641
Annual repair and maintenance costs in CHF[1]	1,582	734	453	591
Annual repair and maintenance factor	0.022	0.036	0.035	0.012
Repair and maintenance costs in CHF per WU	5.82	34.45	8.79	4.56

[1]Based on a three-year average
[2]Based on Gazzarin & Albisser (2010)

dependent variable has values close to zero, we are dealing with a skewed distribution. We therefore apply a logarithmic transformation to adjust this distribution. Several machines report repair and maintenance costs of nil. Since we cannot log-transform these cases, we assume an annual minimum value of CHF 1.00 for repair and maintenance costs.

As a consequence of the dependent variable's logarithmic form, only two functional forms, exponential and power, can be applied for the analysis. Testing both of them the power functional form explains a greater percentage of the variation for all machine types. Accordingly, we apply a power functional form, which is also in line with Morris (1988), Bruhn (2000) and Khoub bakht et al. (2008), who compare several functional forms and in the end choose the power function:

$$y = \beta_0 x_1^{\beta_1} x_2^{\beta_2} \tag{1}$$

The dependent variable y represents the annual repair and maintenance costs expressed as a fraction of the machine's list price. Two independent variables x_1 and x_2 represent annual utilisation and the machine's age, respectively. If further machinery-specific variables such as engine power for tractors are available, the cost function is extendable. All coefficients β are estimated by means of a log-log model[5]. Due to the logarithmic transformation, binary variables (0, 1) must be reformulated towards the values 1 (logarithm equal to zero) and 2.

To deal with outliers, we apply the Iteratively Reweighted Least Squares (IRLS) technique, which weights the observations according to their outlierness. The model is estimated by applying Ordinary Least Squares (OLS's) with the resultant weights of the robust regression. To test for heteroscedasticity, we apply the Breusch-Pagan test. If the H_0 of constant variance is rejected, a Huber-White estimator, also known as a sandwich estimator of variance, is applied (StataCorp 2007, p. 268f).

Starting with all available machine-specific variables, the exclusion of variables is analysed by means of an F-test.

Owing to the definition of the dependent variable, the estimated coefficients cannot be interpreted as marginal costs per year. To enable such an interpretation, the marginal effects must be calculated separately. While w represents the value list price of the machine type in question, the marginal costs (MC) for variable x_1 are:

$$MC_{x_1} = w\frac{\partial y}{\partial x_1} = w\beta_0\beta_1 x_1^{\beta_1 - 1} x_2^{\beta_2} \tag{2}$$

The marginal effect is calculated by inserting mean values for all continuous variables. For binary variables, the marginal effect is calculated by changing the binary variable's value.

Aggregation towards Accumulated Costs

After the annual repair and maintenance costs have been estimated, an aggregation is required in order to obtain the repair and maintenance factor representing the accumulated costs for the machine's estimated service life u (e.g. 10,000 hours for tractors). We therefore think of the estimated service life as the product of x_1 work units per year and a reference length of service of u/x_1. The variable x_2 representing the machine's age is supplemented with indices i extending from the first year of service until u/x_1, the last year of service in which the estimated service life is concluded. Based on equation 1, the repair and maintenance factor RMF can be calculated by summing the annual cost function over all years i:

$$RMF = \Sigma_{i=1}^{u/x_1} y_i = \beta_0 x_1^{\beta_1} \Sigma_{i=1}^{u/x1} x_{2i}^{\beta_2} \tag{3}$$

In other words, the estimated cost function (equation 1) is applied for each year and summed up.

To analyse the impact of different annual utilisations on the repair and maintenance factor, Equation 3 is applied for several annual utilisations (x_1) and matched lengths of service (u/x_1) covering a wide range of operating versions (e.g. for tractors, 1,000 hours a year over 10 years vs. 222 hours a year over 45 years). Since the aggregation takes place on an 'annual' level, the length of service must be an integer.

4. Results

Tables 2 to 5 present the regression estimates for annual repair and maintenance costs expressed as a fraction of the machine's list price for tractors, ploughs, mowers and self-loading trailers, respectively. Due to the weighting from the robust regression, one observation for each of the estimates explaining repair and maintenance costs for ploughs and self-loading trailers is omitted. As regards the F-Test, we can reject the

[5] $\ln y = \ln\beta_0 + \beta_1 \ln x_1 + \beta_2 \ln x_2$

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Table 2: Regression estimates for annual tractor repair and maintenance costs

Variable	Unit	Coefficient	Standard Error	T-Value	P-Value	Marginal Effect in CHF
Constant	–	−6.74	0.53	−12.81	<0.001	–
Annual utilisation	hours	0.51	0.05	9.99	<0.001	2.67
Age	years	0.28	0.04	6.85	<0.001	19.92
Engine power	HP	−0.21	0.09	−2.20	0.028	−3.96
Wide-base tyre	binary	0.17	0.07	2.40	0.017	172.34
Two-wheel drive	binary	−0.22	0.10	−2.26	0.024	−203.30

HP = horsepower
No. of observations: 655
F (5,649) = 27.3; P-Value: <0.001
R^2 = 0.20

Table 3: Regression estimates for annual plough repair and maintenance costs

Variable	Unit	Coefficient	Standard Error	T-Value	P-Value	Marginal Effect in CHF
Constant	–	−5.38	0.45	−12.01	<0.001	–
Annual utilisation	hectare	0.36	0.10	3.74	<0.001	11.38
Age	years	0.32	0.10	3.06	0.003	13.75

No. of observations: 126
F (2,123) = 9.0; P-Value: <0.001
R^2 = 0.13

Table 4: Regression estimates for annual mower repair and maintenance costs

Variable	Unit	Coefficient	Standard Error	T-Value	P-Value	Marginal Effect in CHF
Constant	–	−7.37	0.81	−9.07	<0.001	–
Annual utilisation	hectare	0.47	0.13	3.47	0.001	4.24
Age	years	0.45	0.14	3.24	0.002	21.85
Working width	metre	1.25	0.67	1.88	0.064	241.10
Drum mower	binary	−0.68	0.28	−2.46	0.016	−176.12

No. of observations: 90
F (4,85) = 6.2; P-Value: <0.001
R^2 = 0.23

Table 5: Regression estimates for annual self-loading trailer repair and maintenance costs

Variable	Unit	Coefficient	Standard Error	T-Value	P-Value	Marginal Effect in CHF
Constant	–	−4.71	0.68	−6.93	<0.001	–
Annual utilisation	hectare	0.42	0.05	8.38	<0.001	1.89
Age	years	0.16	0.09	1.90	0.059	5.16
Volume	cubic metre	−0.83	0.17	−4.95	<0.001	−20.08
Knives	number	0.12	0.07	1.84	0.068	6.44

No. of observations: 210
F (4,205) = 25.0; P-Value: <0.001
R^2 = 0.33

hypothesis that the estimated coefficients are simultaneously equal to zero for all machine types. The coefficients of determination (R^2) range between 0.13 and 0.33.

For tractors, annual utilisation and age exert highly significant effects (Table 2). The estimated exponent for annual utilisation is far below one (0.51). Accordingly, repair and maintenance costs increase in a disproportionately low manner compared to utilisation. This effect is also confirmed by the marginal effect, which is based on sample mean values. The marginal effect of an additional hour of utilisation is CHF 2.67, which is far below the average hourly repair and maintenance costs (CHF 5.82/h, Table 1). An additional year in service increases annual costs by CHF 19.92. Tractors with more powerful engines have relatively lower costs. In this respect, it is important to note that younger tractors have larger horse power[6].

Wide-base tyres lead to additional repair and maintenance costs of about CHF 172.34 per year (marginal effect based on sample mean values). Similarly, compared to the base-case equipment with four-wheel drive, the cost of two-wheel drive tractors is about CHF 203.30 lower a year.

The estimated exponent for annual plough utilisation is highly significant, and indicates that repair and

[6] Horse power and age are negatively correlated (−0.64).

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Table 6: Repair and maintenance factor (RMF) for different operating versions

LS in Years	Tractors		Ploughs		Mowers		Self-loading trailers	
	AU in hours	RMF	AU in ha	RMF	AU in ha	RMF	AU in cartloads	RMF
10	1,000	0.26	100	0.39	120	0.37	550	0.15
15	667	0.34	67	0.57	80	0.54	367	0.21
20	500	0.43	50	0.75	60	0.71	275	0.25
25	400	0.50	40	0.93	48	0.88	220	0.30
30	333	0.58	33	1.10	40	1.04	183	0.34
35	286	0.65	29	1.27	34	1.21	157	0.38
40	250	0.72	25	1.44	30	1.38	138	0.42
45	222	0.79	22	1.62	27	1.54	122	0.46

AU = Annual utilisation
LS = Length of service
RMF = Repair and maintenance factor; accumulated repair and maintenance costs reported in relation to the machine's list price

maintenance costs increase in a disproportionately low manner (value below 1) if annual utilisation increases (Table 3). The marginal effect of an additional hectare amounts to CHF 11.38, which represents less than a third of the average repair and maintenance costs per hectare (Table 1). Costs for ploughs increase with age: An additional year in service leads to additional repair and maintenance costs of about CHF 13.75 per year. According to the F-test, the number of ploughshares can be excluded as an explanatory variable.

For mowers, the results for annual utilisation and age are similar to those of the preceding machines, leading to marginal effects of CHF 4.24 per additional hectare and CHF 21.85 per additional year in service, respectively (Table 4). Working width is only significant on the 10% level. Applying sample mean values for marginal effects an additional metre of working width increases annual costs by CHF 241.10. Lastly, the equipment with discs (base case) or drums (also called a cylinder mower) is important. Drum mowers, which represent 40% of the sample, have lower annual repair and maintenance costs (CHF 176.12), reflecting their lower mechanical complexity.

Whereas the annual utilisation of self-loading trailers exerts a highly significant effect, age is only significant on the 10% level (Table 5). Volume measured in cubic metres refers to the size of cartloads. The bigger the machine, the lower are the relative annual repair and maintenance costs[7]. Applying sample mean values for marginal effects an additional cubic metre of volume reduces annual costs by CHF 20.08. By contrast, an additional knife increases repair and maintenance costs by CHF 6.44 per year.

Table 6 shows the results for the repair and maintenance factors (RMFs) which represent the accumulated repair and maintenance costs over the entire service period reported in relation to the machine's list price. Full utilisation of estimated service life is assumed for all operating versions presented (annual utilisation and reference lengths of service).

The results show clearly that the degree of machine utilisation exerts a huge influence on accumulated repair and maintenance costs. For example, given an annual utilisation of 400 hours and a service life of 25 years, an RMF of 0.50 of the tractor's list price is spent on repair and maintenance. Increasing annual utilisation towards 500 hours with a reference service life of 20 years reduces repair and maintenance costs by about 0.07 of the tractor's list price towards an RMF of 0.43. For the other machines also, an increase in annual utilisation leads to substantially lower repair and maintenance costs.

5. Discussion

Limitations on the interpretation of the results exist for two reasons. Firstly, looking at the coefficients of determination, no more than one-third of the variance can be explained. While Morris (1988) presents similar coefficients of determination for the repair cost functions per hour, it has to be noted that the mentioned studies dealing with either accumulated repair and maintenance costs or depreciation show clearly higher coefficients of determination. Accordingly, there are further important influences on repair and maintenance costs which, could not be taken into account, e.g. make of machinery, additional equipment, operating conditions (e.g. soil type in the case of ploughs), or the treatment of machinery by farm workers, which also includes use of the machinery on different farms (cooperative machine usage). Secondly, based on a survey, repair and maintenance costs must to be understood as minimum values. As mentioned in the data section, farm workers' labour input for repair activities on-farm is not included in the survey data. Accordingly, working time cannot be rated and is missing from the analysis. In addition, while it is unlikely that farmers will inflate the costs with respect to bills from service agents or for material expenses, we cannot rule out the possibility of farm managers forgetting to state costs for individual repairs.

For tractors, we can compare our results for accumulated repair and maintenance costs with the literature. Analysing 172 tractors in Germany with an average annual utilisation of 898 hours, Bruhn (2000) reports accumulated costs of 0.39 of the machine's list price[8]. Our results for an annual utilisation of 1000 and 667 hours – 0.26 and 0.34, respectively – are of a similar

[7] The correlation between volume and age is −0.18.

[8] These tractors are selected out of a sample of 210 tractors. On average, the tractors of the whole sample are more powerful (178 horsepower compared to 75 horsepower) and newer (4.2 years old compared to 20 years old) than those in the Swiss sample.

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magnitude. The cost function proposed by Wendel (1989) for 27 90-kW-class (122 horsepower) German tractors with an annual utilisation of 803 hours can be converted into accumulated repair costs of 0.50 using list prices from the reference years (KTBL 1990), which is in excess of our estimates for similar annual utilisations. For the USA, the American Society of Agricultural Engineers (ASAE, 2003a and 2003b) gives repair and maintenance factors resulting in total costs of 0.30 (four-wheel drive and 10,000 hours estimated service life). Our results for an annual utilisation of 1,000 and 667 hours – 0.26 and 0.34, respectively – are similar. Conversely, for two-wheel drive tractors, the ASAE reports far higher repair and maintenance costs of about 0.7 (10,000 hours estimated service life), indicating a substantial technical difference between the two types of tractors. In our results, two-wheel tractors have slightly lower costs than four-wheel tractors (Table 2).

Another four analyses for tractors show different results. Ward et al. (1985) find accumulated repair costs of above 2.00 for four-wheel tractors used in forestry work in Ireland. Rotz (1987) reports accumulated costs of 1.00 for four-wheel-drive tractors for the USA. For the UK, Morris (1988) estimates accumulated repair and maintenance costs by means of his two-stage approach at 0.80 of the machine's list price based on 50 tractors with an annual utilisation of about 800 hours. Finally, Khoub bakht et al. (2008) arrive at accumulated costs as high as 0.88, based on 102 (type MF285) tractors in Iran. All four analyses with substantially higher values either originate in a region with a different climate and agricultural scenario (Khoub bakht et al., 2008) or are older (i.e. date from the 1980s: Ward et al. 1985, Rotz 1987 and Morris 1988). Similarly, Bruhn (2000) stresses that – compared to older analyses – technical improvement has occurred in Germany, leading to lower repair costs.

For ploughs and mowers, a different definition of work units only allows for an indirect comparison with the ASAE (2003a). Assuming a slightly larger estimated service life, the ASAE gives repair and maintenance costs of 1.01 for mouldboard ploughs, which tallies with our estimates for annual utilisations of 33 and 40 hectares. As regards mowers, the ASAE's repair and maintenance costs are 1.49, a value corresponding to our results for annual utilisation of around 27 hectares. Here, we must mention that the ASAE uses an utilisation value more than twice that of the mowers in Switzerland.

The importance of annual utilisation as an explanatory factor for repair and maintenance costs has been reported in just one study. Applying a covariance analysis, Bruhn (2000, p. 72) reports a statistically significant correlation between per-hour repair costs and annual utilisation for German tractors. Consequently, annual utilisation is used to calculate repair costs per work unit, but omitted as an explanatory variable in the subsequent regression analysis.

6. Conclusions

In this paper, we analyse repair and maintenance costs for four agricultural machine types in Switzerland, applying a two-stage approach in order to derive repair and maintenance factors. Compared to the literature, we introduce two modifications: Firstly, we use cross-sectional data from a survey instead of accumulated data on repair and maintenance costs and working units, with the result that data requirements can be substantially lowered. Secondly, this approach allows the introduction of more than one influencing variable.

Although no more than one-third of the variances can be explained, the analysis reveals statistically significant influences. For all four machines analysed, both age and annual utilisation significantly influence annual repair and maintenance costs. In addition, the regression analyses show that machine-specific variables are also important, and must be taken into account when analysing repair and maintenance costs.

The marginal effect of an additional year in service is positive for all machines. Generally speaking, the older the machine, the higher the annual repair and maintenance costs. It is in line with the literature that repair and maintenance costs tend to increase with the age of the machine, possibly owing to material fatigue and the higher costs of spare parts for older machines.

The introduction of annual utilisation as an explanatory variable helps us understand that the intensity of machine usage plays a major role in repair and maintenance costs. A central conclusion of this paper is that the repair and maintenance factor depends not only on (accumulated) utilisation, as reported in the literature, but also on annual utilisation. Consequently, assuming that the machine's estimated service (or useful) life is completely exploited, repair and maintenance costs depend on the length of time during which the estimated service life is utilised, a fact which, to our knowledge, has so far not been taken account of in the literature. Accordingly, farm-management literature should also report machinery repair and maintenance factors along with the reference annual utilisation.

Because estimated exponents for annual utilisation are less than one, an increase in annual utilisation leads to a decrease in repair and maintenance costs per work unit. This effect is confirmed for all machinery types analysed. We therefore conclude that there is an economy-of-scale effect. Hence, at least some repair and maintenance costs are incurred by activities performed independently of annual utilisation. Consequently, Swiss agriculture could achieve substantial savings in repair and maintenance costs by increasing its annual utilisation of machinery. The higher the utilisation rate, the lower the repair and maintenance costs per work unit. This tallies with the above-mentioned influence of length of service life. From a repair-and-maintenance-costs perspective, a short length of service coupled with high annual utilisation is advantageous. Conversely, lowering annual utilisation and extending the length of service of a machine leads to additional repair and maintenance costs. In this respect, the inter-farm use of machinery may represent a promising strategy for Swiss agriculture.

According to the literature, annual utilisation has a similar effect on depreciation, at least for tractors. If the market price of second-hand tractors is used to determine the current value of the machine and hence depreciation, a high annual utilisation leads to lower

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depreciation and interest charges per work unit (Wilson and Davis 1998, Wilson 2010).

As regards the application of the repair and maintenance factors for farm-management literature presented here, it must be borne in mind that, owing to the limitations of the data used, the values are to be understood as minimum figures. Consequently, a rounding-up of these figures is recommended.

The suggested approach constitutes a useful tool for all agricultural machine types analysed, leading to repair and maintenance factors comparable to those in the literature. It also offers the possibility of broad application via cross-sectional data, which is less costly than the recording of accumulated repair and maintenance costs.

Further analyses of other machinery types must be carried out in order to update the repair and maintenance factor database of the Swiss report on machinery costs. In addition, an important question to be answered in future is whether technological improvement still leads to lower repair and maintenance costs, as claimed by Bruhn (2000). If so, a regular revision of repair and maintenance factors for farm management literature would be essential.

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REFERENCES

Agri Benchmark, 2009. *Cash Crop Report 2009: Benchmarking Farming Systems Worldwide*. Braunschweig: Agri Benchmark, von Thünen Institut (vTI).

Albisser, G., Gazzarin, Ch. and Gärtner D., 2009. *Maschinenkosten in der Praxis: Auslastung, Nutzungsdauer und Reparaturkosten ausgewählter Landmaschinen auf Schweizer Betrieben*. ART-Bericht No. 711, Ettenhausen: Agroscope Reckenholz-Tänikon Research Station.

ASAE, 2003a. Agricultural Machinery Management Data D497.4 FEB03. American Society of Agricultural Engineers. *ASAE Standards*, 2003, pp. 373–380.

ASAE, 2003b. Agricultural Machinery Management EP496.2 FEB03. American Society of Agricultural Engineers. *ASAE Standards*, 2003, pp. 367–372.

Bruhn, I., 2000. *Erhebung zu Reparaturkosten von Maschinen auf Grossbetrieben, dargestellt für Traktoren und Mähdrescher*. Forschungsbericht Agrartechnik No. 357. Dissertation, Christian-Albrechts-Universität zu Kiel.

Dumler, T. J., Burton, R. O. and Kastens, T. L., 2003. Predicting Farm Tractor Values through Alternative Depreciation Methods. *Review of Agricultural Economics, 25*(2), pp. 506–522.

Gazzarin, Ch. and Albisser, G., 2010. *Maschinenkosten 2010*. ART-Bericht No. 733, Ettenhausen: Agroscope Reckenholz-Tänikon Research Station.

Khoub bakht, G. M., Ahmadi, H., Akram, A. and Karimi, M., 2008. Repair and Maintenance Cost Model for MF285 Tractor: A Case Study in Central Region of Iran. *American-Eurasian Journal of Agricultural & Environmental Sciences*, 4(1), pp. 76–80.

KTBL, 1990. *KTBL-Taschenbuch Landwirtschaft*, 15th edition, Darmstadt: KTBL, Association for Technology and Structures in Agriculture.

Morris, J., 1988. Tractor repair costs. *Farm Management*, 6(10), pp. 433–441.

Rotz, C. A., 1987. A Standard Model for Repair Costs of Agricultural Machinery. *Applied Engineering in Agriculture,* 3(1), pp. 3–9.

StataCorp, 2007. *Stata User's Guide, Stata Statistical Software*. Release 10, College Station, TX: StataCorp LP.

Stiens, H. and Windhüffel U., 1990. Zur Kalkulation des Reparaturrisikos. *Agrarwirtschaft,* 39(5), pp. 148–154.

Ward, S. M., McNulty, P. B. and Cunney, M. B., 1985. Repair Costs of 2 and 4 WD Tractors. *Transactions of the ASAE*, 28(4), pp. 1074–1076.

Wendel, G., 1989. Reparaturkostenuntersuchungen an Ackerschleppern. *Grundl. Landtechnik,* 39(1), pp. 17–21.

Whitehead, E.N.C. and Archer, C.G., 2010. *Guide to Machinery Costs. Agricultural Development Support Services Directorate KwaZulu-Natal South Africa*, available at: <www.kzndae.gov.za/AgricultureDevelopmentServices/AgriculturalEconomics/GuidetoMachineryCosts.aspx>, [accessed 4 October 2011].

Wilson, P. and Davis, S., 1998. Estimating Depreciation in Tractors in the UK and Implications for Farm Management Decision-Making. *Farm Management*, 10(4), pp. 183–193.

Wilson, P. and Tolley, C., 2004. Estimating tractor depreciation and implications for farm management accounting. *Farm Management*, 12(1), pp. 5–16.

Wilson, P., 2010. Estimating Tractor Depreciation: The Impact of Choice of Functional Form. *Journal of Farm Management*, 13(12), pp. 779–818.

Wu, J. and Perry, G. M., 2004. Estimating Farm Equipment Depreciation: Which Functional Form is Best? *American Journal of Agricultural Economics*, 86(2), pp. 483–91.

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