WEATHER RISK AND MACHINERY COSTS – A MONTE CARLO SIMULATION FOR THE WHEAT HARVEST

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Abstract

In eastern Switzerland there is a substantial weather risk during the wheat harvest. Increasing the number of available combine harvesters reduces harvest losses due to bad weather conditions, whilst increasing machinery costs. Simulating weather risk, we analyse harvest losses and machinery costs. In doing so, we apply both a deterministic and a stochastic approach – the latter by means of a Monte Carlo simulation.

The costs per hectare of wheat are higher in the stochastic approach, because bad weather conditions lead to high costs. There is no difference between the two approaches in terms of minimum costs, which in both cases are achieved by a density of 20 harvesters per 1000 hectares. Calculation results are lower than the actual density, which is around 30 harvesters. One explanation for this may be that farmers seem more concerned with decreasing harvest losses than with reducing machinery costs. They are willing to pay more for the harvest process than is strictly necessary, viewing a high density of harvesters as a kind of insurance for weather risk.

Keywords: weather risk, wheat harvest, Monte Carlo simulation

1 Introduction

Owing to Swiss agricultural policy, cereal prices are three times as high in Switzerland as in Germany or France. The price for the highest quality of wheat, for example, is 570 Swiss Francs (CHF), or almost 360 Euro per tonne. Accordingly, there is a considerable incentive for farmers to prevent harvest losses. During the main harvest period in early August, weather conditions are challenging. In order to reduce potential losses owing to weather risk, a high density of combine harvesters makes sense. In 2003 there were 3538 combine harvesters in Switzerland (SCHWEIZER BAUERNVERBAND 2006). Crops that require threshing (all cereals, including both maize and oilseed rape) account for around 175,000 ha. On average, each combine harvester is used for 50 hectares a year. Since combine harvesters are built to thresh between 2000-3000 ha, this yields a useful life of 40-60 years. Given that technical improvements are bound to occur over such a long time period, it is rather implausible for a combine harvester to remain in service for this length of time. As a result, combine harvesters are not used efficiently in Switzerland, which is reflected in high machinery costs. Whereas

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the threshing of a hectare costs around CHF 400 in Switzerland, in southern Germany the reference cost is a little over half of this (CHF 230, or EUR 145).

From an economic point of view, the trade-off between risk of harvest losses and machinery costs is of interest. Accordingly, we simulate the wheat harvest for a given area using different numbers of harvesters. To take into account the weather risk, we apply a Monte Carlo simulation.

2 Cost Calculation and Monte Carlo Simulation

2.1 Wheat harvest in the Frauenfeld region

The aim of this paper is to analyse the costs of cereal harvest. We focus on the wheat harvest, which comprises calendar weeks 31 and 32, because it represents the work peak of the cereal harvest. Other cereals besides wheat – summer barley, oats, spelt and triticale – become ripe over the same period. Since combine harvesters are normally used by specialised contractors, analysis takes place at a regional level – hence our choice of an area of 1000 hectares in the Frauenfeld region. Located in the plain area of eastern Switzerland, the Frauenfeld region lies approx. 500 meters above sea level. The annual rainfall amounts to 1100 mm. The average yield is 6 tonnes per hectare. A second reason for focusing on a specific region is the need for local weather data.

Our analysis only focuses on costs during the harvest, which can be divided into two components – machinery costs, and costs related to harvest losses. The latter comprise the price reduction due to outgrowth, and the drying costs if the moisture content of grains is above 15 per cent. Unlike farmers in other countries, Swiss farmers must pay for drying in case of high moisture.

As the number of combine harvesters influences both cost components, we alter it in the simulation. Starting with 5 combine harvesters for the 1000 hectares, we increase the number stepwise (plus 5) until we reach 50 machines.

The analysis is carried out twice, depending on the modelling of weather risk. In the first, deterministic, case, the risk is considered fixed. In the second case, however, we treat the weather risk as a stochastic variable.

2.2 Deterministic Case

This calculation is performed in six steps. In a **first step,** we determine the number of combine harvesters for the area analysed (e.g. 5), which gives us the number of hectares per harvester (e.g. 200). We assume that only one type of harvester is used (working width around 5 m, 150 kW), and therefore calculate the machinery cost per harvested hectare based on AMMANN (2006). The variable costs are constant, e.g. the use of fuel does not depend on the capacity utilisation. In order to divide the fixed cost by the number of hectares, we bear in mind that harvesters are also used for cereals other than wheat – for example, winter barley is harvested before wheat, while the maize harvest comes afterwards. The wheat harvest accounts for around 60 per cent of a harvester's capacity utilisation: if 200 hectares of wheat are threshed, the annual capacity utilisation comes to 333 hectares.

A **second step** concentrates on the time requirement per combine harvester. Assuming a field size of 2 ha, and a distance travelled by the harvester to reach the field of 3 km, according to the work-budget system developed by SCHICK and STARK (2003), a combine harvester has a time requirement of 1.09 hours per hectare. Accordingly, 218 hours are required for the assumed 200 hectares per combine harvester.

For the **third step,** we look at the available harvesting days, which depend on two factors: Probability of a harvest opportunity, and duration of grain dormancy. Both variables can be treated either as deterministic or stochastic. In this subsection, we concentrate on the deterministic case. Based on local weather data, the probability of a harvest opportunity during calendar weeks 31 and 32 is 50 per cent (LUDER 2002). According to a wheat expert, we assume 5 days' duration of grain dormancy given a specific wheat variety. The farmers of the Frauenfeld region grow different varieties of wheat. We assume the maximum difference of ripeness among varieties, accounting for seven days. Accordingly, a value of 12 days is used for grain dormancy. The impact of this assumption is analysed in a sensitivity analysis in section 4. In order to determine the number of available harvest days, we must multiply the probability of a harvest opportunity by the duration of grain dormancy (0.5 x 12 days = 6 days). Later on, outgrowth would take place. We assume that there is a quality difference between the first 20 days of outgrowth and the time afterwards, which is unlimited. Once again, we use a 50 per cent probability of a harvest opportunity for the first 20 days of outgrowth (0.5 x 20 days = 10 days).

The **fourth step** comprises the calculation of available harvest hours. Based on the work done by LUDER (1984), we introduce nine different time frames for harvesting conditions. We distinguish between three situations: normal harvest, outgrowth in the first 20 days, and outgrowth thereafter:

- As seen above, there are six available days in the normal harvest. For six hours a day, the moisture content is 15 per cent, for which no drying process is required. For two further hours, the moisture content is around 16 per cent, which makes drying necessary, and for which the reference costs per hectare are CHF 52. Finally, another two hours with a moisture content of 17 per cent (CHF 76 per ha) and 18 percent (CHF 100 per ha), respectively, can be used. All in all, 60 hours are available for harvest [6 x (6+2+1+1)].
- For outgrowth in the first 20 days, another four time frames exist, similar to the normal harvest. In total, 100 hours are available [10 x (6+2+1+1)]. In addition to the drying costs, outgrowth in the first 20 days implies a loss of CHF 750 per ha.
- Outgrowth after 20 days is accompanied by a loss of CHF 1200 per ha.

In a **fifth step,** the required harvesting hours (step 2) and available harvesting hours (step 4) are combined. Assuming an optimal procedure, analysis is performed stepwise starting with the best harvesting conditions. If the required harvest time is greater than the best time frame, we move on to the second-best time frame, and so on. Finally, if all eight time frames of normal harvest and outgrowth are smaller than the required harvest time, the rest of the harvest is carried out under outgrowth after 20 days.

Drying and outgrowth costs are calculated for all time frames in a **sixth and final step,** yielding the costs due to harvest losses. These are added to the machinery costs from the first step to give the total costs per harvester. Dividing this figure by the number of hectares (per harvester from step one) yields the total costs per hectare, which is the same for all 1000 hectares under consideration.

2.3 Stochastic Case

The procedure for the stochastic case is similar to that of the deterministic case. In order to take into account weather risk and the volatility of grain dormancy, we carry out a Monte Carlo simulation. Accordingly, the probability of good weather conditions and the duration of grain dormancy are treated as stochastic variables. Both follow a normal distribution and use the above-mentioned values as the mean. While the standard deviation of the probability of a harvest opportunity is 15 per cent (expected value: 50 per cent), we assume a standard deviation of 2 days for the duration of grain dormancy (expected value: 12 days). By contrast, the duration of outgrowth is still handled in a deterministic way (first phase 20 days, unlimited afterwards).
Both stochastic variables are calculated 1000 times by Microsoft Excel. Accordingly, the above-mentioned steps 2-6 are carried out 1000 times as a Monte Carlo simulation. The results enable the calculation of mean (expected value) and standard deviation for the harvest losses per hectare.

3 Results

First of all, we focus on the results for the deterministic case (Table 1). Starting with 5 combine harvesters, machinery costs are low per hectare (CHF 237), rising stepwise up to CHF 1035 (50 harvesters). By contrast, losses decline with additional harvesters. Given 30 harvesters or more, there are no harvest losses. Looking at cost percentages, balance is achieved with 10 harvesters.

Table 1: Results for the Deterministic Case for one Hectare

Number of combine harvesters	Machinery costs in CHF	Costs due to harvest losses in CHF	Total costs in CHF	Proportion of machinery costs in %	Proportion of costs due to harvest losses in %
5	237	710	948	25	75
10	296	352	648	46	54
15	388	154	542	72	28
20	481	21	501	96	4
25	573	9	582	98	2
30	665	0	666	100	0
35	758	0	758	100	0
40	850	0	850	100	0
45	943	0	943	100	0
50	1035	0	1035	100	0

Total costs are shown as a U-shaped curve (Figure 1). Minimum costs are achieved with 20 harvesters. Adding further harvesters machinery costs exceed harvest losses.

Figure 1: Results for the Deterministic Case

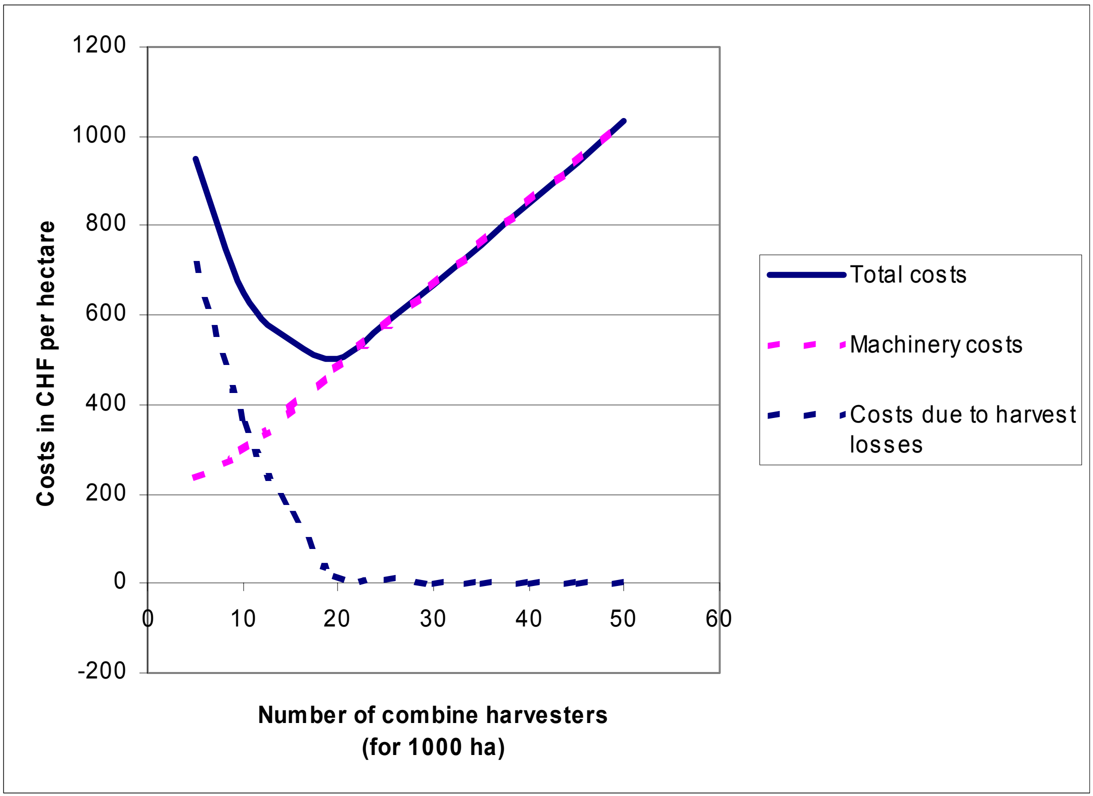


Table 2 shows the results for the stochastic case, which, generally speaking, are similar to those of the deterministic case.

For no number of harvesters are harvest losses equal to zero. Instead, they decrease towards CHF 11 per hectare. Although the expected value is fairly low, harvest losses vary greatly. Adding and subtracting twice the standard deviation from the expected value gives the 95 per cent confidence interval. For obvious reasons, the confidence interval cannot fall below zero – e.g. for 20 harvesters, the 95 per cent confidence interval for harvest losses ranges from CHF 0 to CHF 398, and for 50 harvesters, the range is CHF 0 to CHF 249. For the latter the upper end is almost 23 times the expected value.

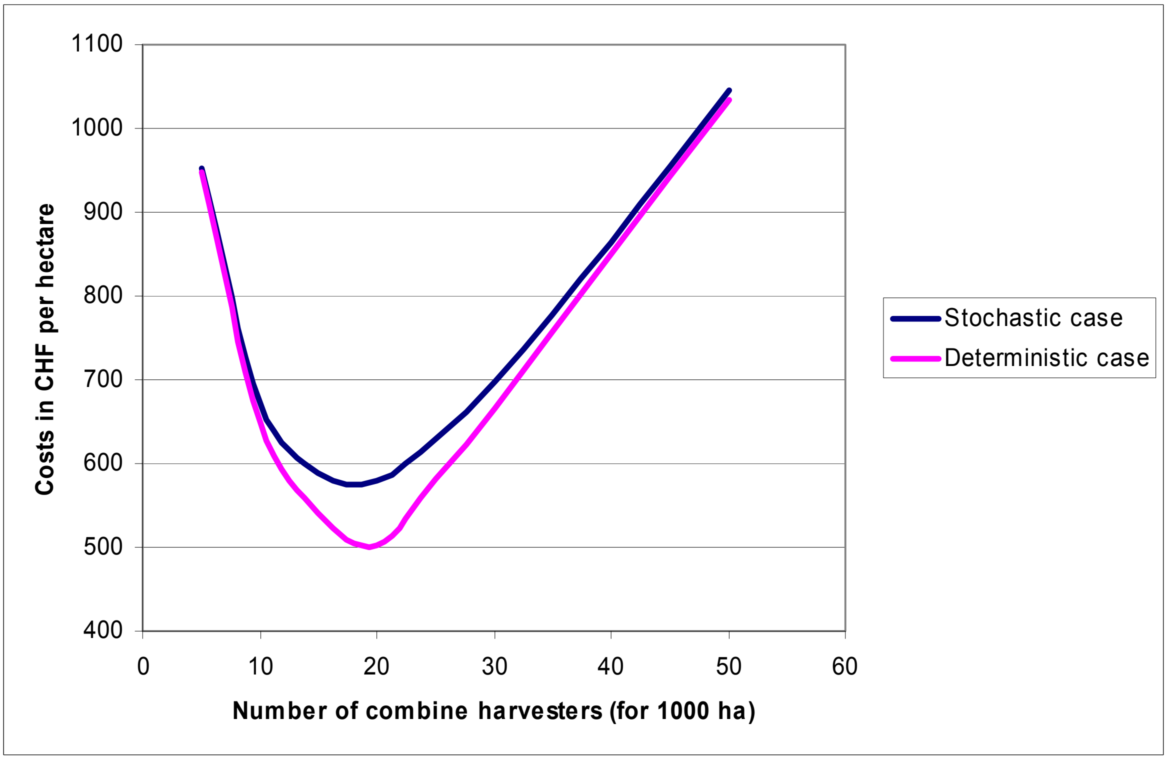
Similarly to the deterministic case, minimum costs are achieved with 20 harvesters, although the minimum value of CHF 579 is CHF 78 or 16 per cent higher than in the deterministic case. Once again, the impact of bad weather conditions is responsible for the difference.

Table 2: Results for the Stochastic Case for one Hectare

Number of combine harvesters	Machinery costs in CHF	Costs due to harvest losses in CHF expected value	Costs due to harvest losses in CHF standard deviation	Total costs in CHF	Proportion of machinery costs in %	Proportion of costs due to harvest losses in %
5	237	715	175	952	25	75
10	296	375	200	671	44	56
15	388	200	168	588	66	34
20	481	98	150	579	83	17
25	573	56	122	629	91	9
30	665	31	101	697	95	5
35	758	19	81	777	98	2
40	850	13	73	863	99	1
45	943	11	77	954	99	1
50	1035	11	119	1046	99	1

Figure 2 depicts the cost curves of both the deterministic and stochastic cases. The clear difference between the two (in the region between 10 and 30 harvesters) is the result of the impact of bad weather conditions.

Figure 2: Total Costs for Both Cases



4 Sensitivity Analysis

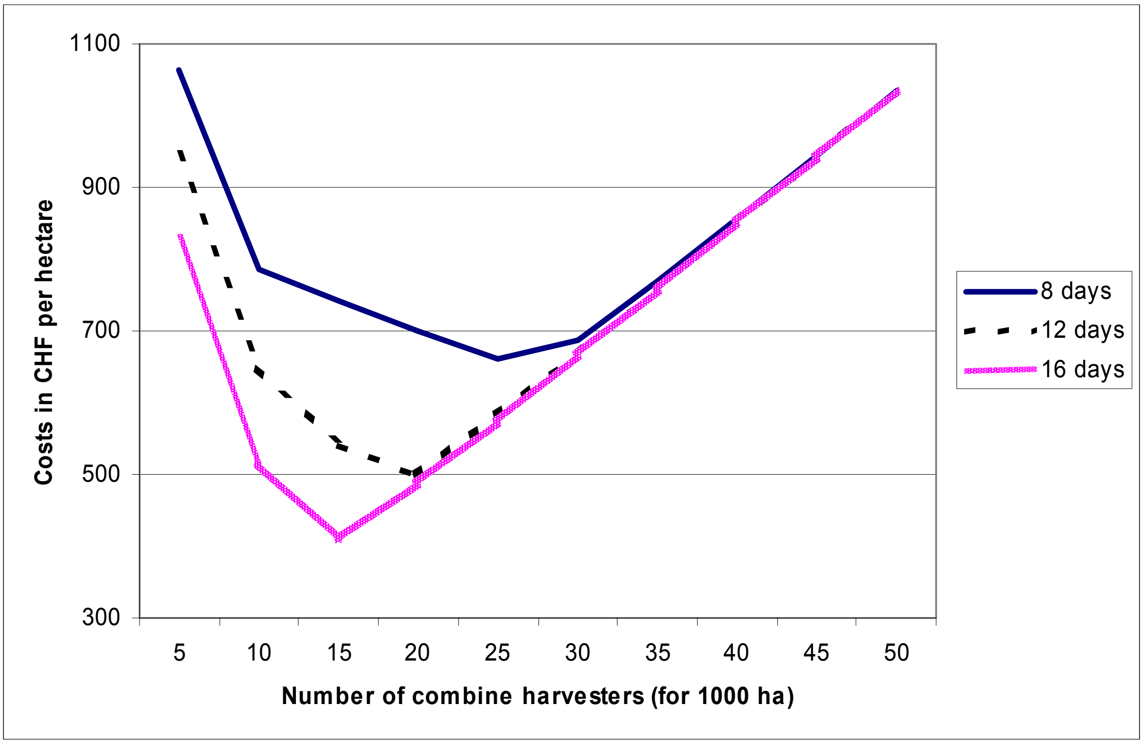
The expected value for grain dormancy is the most critical assumption in our analysis. To assess the impact of the assumption, we carry out a sensitivity analysis for the deterministic case. Grain dormancy is thus varied between 8 and 16 days, which seems to be a realistic range. The resultant total costs are presented in Table 3. Grain dormancy exerts an important influence. If dormancy is 14 days instead of 12, minimum costs are achieved with 10 combine harvesters. Conversely, with a dormancy of 8 days, minimum costs are achieved with 25 combine harvesters.

Table 3: Total Costs for Different Grain Dormancies

Number of combine harvesters	8 days	10 days	12 days	14 days	16 days
5	1064	1006	948	889	831
10	785	715	648	582	516
15	741	641	542	**443**	**409**
20	701	**568**	**501**	492	487
25	**661**	591	582	575	573
30	686	674	666	665	665
35	770	760	758	758	758
40	856	850	850	850	850
45	943	943	943	943	943
50	1035	1035	1035	1035	1035

Figure 3 shows the total cost curves for 8, 12 and 16 days of grain dormancy.

Figure 3: Total Costs for Different Grain Dormancies



5 Conclusions

In this paper, we simulate both machinery costs and costs due to weather risk for the wheat harvest in eastern Switzerland. The comparison of the deterministic and stochastic approaches shows substantial differences between the two, with expected total costs being clearly higher in the stochastic case. The reason for this is the influence of bad weather conditions. The situation here, in other words, is asymmetric, with extremely good weather conditions having only a minor impact (low drying costs), while extremely bad weather conditions result in high costs for drying and outgrowth.

The density of combine harvesters or number of combine harvesters per 1000 hectares exerts a major influence on total costs. In both cases (deterministic and stochastic), the minimum cost is achieved with 20 harvesters per 1000 hectares. Considering in addition a range of grain dormancy, the minimum cost can be found at between 15 and 25 harvesters per 1000 hectares. These results are lower than the actual density, which is around 30 combine harvesters during the wheat harvest[1].

An explanation for this could be that farmers seem more intent on reducing harvest losses than on reducing machinery costs. They are willing to pay more for the harvest process than is strictly necessary, perceiving a high density of harvesters as a kind of insurance against weather risk. In other words, there is evidence of an aversion on the part of Swiss farmers towards weather risk.

Nevertheless, our results suggest that there is a substantial potential for decreasing costs during the harvest by reducing the number of harvesters used.

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[1] All 3538 combine harvesters in Switzerland are used during the harvest of the wheat, which accounts for 60 per cent of the crops requiring threshing and covers 175,000 hectares (SCHWEIZER BAUERNVERBAND 2006), resulting in a density of 30 combine harvesters per 1000 ha [175,000 x 0.6/ 3538 = 29.7].