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The hedging efficiency of wheat futures in various types of farms in Germany

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Abstract

Purpose – Farmers are often advised to hedge their commodity prices on the commodity futures exchange, without sound scientific evidence to support this. This paper questions this rash advice and analyzes the impact of various hedging strategies based on wheat futures for a large sample of farms in Germany.

Design/methodology/approach – Historical simulation and a whole-farm risk approach are used to evaluate the hedging efficiency for 2,197 German farms over a 21-year study period. We use "adjusted farm profit" as a performance indicator and measure which relative change in profit volatility these farms would have obtained by nine different hedging strategies. Additionally, a cluster analysis was employed to discern farm types that exhibit notably low or high hedging efficiencies.

Findings – Hedging would have only marginally reduced or even increased profit volatility in most cases and across different regions, farm types, and farm sizes. In addition, many farms would even have experienced perverse effects, as hedging would not only have led to increased profit volatility, but also to a reduction in profit levels due to hedging costs and/or losses in futures trading.

Originality/value – This paper presents an in-depth analysis of the effects of hedging based on wheat futures contracts. Unlike previous hedging studies that used synthetic farm models or rather small samples, we use a whole-farm risk approach and conduct a large-scale study of 2,197 farms over a 21-year study period. The study results cast substantial doubt on the conventional wisdom that farmers should be generally more willing to include hedging as an innovative tool into their risk management.

Keywords Agricultural risk management, Commodity futures exchange, Euronext Paris, Hedging, Milling wheat no. 2, Wheat futures contracts, Whole-farm risk

Paper type Research article

1. Introduction

Even a cursory glance at accountancy data shows that German farmers are exposed to high income fluctuations over time (cf. BMEL, 2022). Such fluctuations, with a focus on negative deviations, are known as "*whole-farm risk*" (Berg and Schmitz, 2007; Huirne *et al*., 2007; Binswanger-Mkhize, 2012; Broll *et al*., 2013; Tauser and Cajka, 2014; Doms *et al*., 2018). Whole-farm risk results from the fact that – depending on the production and financial structure – a multitude of upstream random variables ("risk factors") jointly influence how a farm performs economically. Important *risk factors* include volatile costs, yields, and prices of various farm products. Whole-farm risk in Germany (and other countries) is believed to have increased over the last few decades for three main reasons: (1) Climate change is increasingly leading to yield fluctuations and losses in many regions of the world (Lobell and Gourdji, 2012; Hristov *et al*., 2020; Schmitt *et al*., 2022). (2) The phasing out of agricultural price support in the EU exposes farmers to the volatile prices of global markets (von Ledebur and Schmitz, 2011; Bohl *et al*., 2015). (3) In the aftermath of natural and man-made disasters, shocks in global supply and demand can cause vast price fluctuations and even temporary disruptions in supply chains. Exogenous shocks that have caused major disturbances in the world markets include the

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Covid-19 pandemic (OECD, 2021) and Russia's war on Ukraine (FAO, 2022). However, it is believed that uncertainty in global supply and demand and thus price volatility will continue to increase in the future, even without disruptive shocks (OECD and FAO, 2022).

As other entrepreneurs, farmers are generally assumed to be risk-averse decision-makers who strive not only for high levels of income but also for low income volatility (Ziegelbäck and Breuer, 2011; Iyer *et al*., 2020; Muβhoff and Hirschauer, 2020, p. 339). In other words, they are prepared to accept some loss of income (i.e. pay a "*risk premium*") in return for lower income volatility. To identify the best decisions under risk, not only the *level of risk* associated with various entrepreneurial decisions must be taken into account but also the individual farmer's *degree of risk aversion*. Although much research has gone into the elicitation of individual risk preferences, the accuracy of these elicitations is still in doubt (Moschini and Hennessy, 2001; Eckel, 2019; Hertwig *et al*., 2019; Grüner *et al*., 2023). Therefore, practical decision support for farmers is usually limited to quantifying and communicating the risks that are associated with various choices.

Most farms are complex enterprises in that they not only use different inputs, but also produce multiple outputs. As entrepreneurs, it is not the fluctuations of a single upstream risk factor, such as the price or yield of a single product, that farmers are averse to and try to avoid. Rather, they are averse to negative income fluctuations that could jeopardize their standard of living, the development of their farm or even its existence. To make informed choices under risk, farmers must know the whole-farm economic risks ("whole-farm risks") that are associated with those choices. Otherwise, cognitive errors can lead to incorrect decisions that have unintended consequences or even perverse effects. Such effects can occur, for example, when measures aimed at reducing entrepreneurial risk impair a *natural hedge*, that is a risk reduction mechanism that is effective without the farmer's intervention. Take the pronounced negative correlations between potato yields and prices (BLE, 2022; USDA, 2023, p. 12) that are caused by the market mechanism of supply and demand. A perverse effect occurs, for example, when farmers unintentionally – and possibly unnoticed – increase whole-farm risk precisely because they use costly price hedging instruments that obstruct the "natural" compensation of low crop yields through high prices (Urban, 2019; Duden *et al*., 2019).

Before measuring whole-farm risk – and the impact of a risk management activity on whole-farm risk – two decisions must be made: first, we must specify a metric of the farm's economic performance ("performance indicator") that is meaningful in the respective context. Examples are the total gross margin or cash flow (in diversification, insurance or hedging contexts) or the net present value (in investment contexts). Second, we must identify statistical dispersion measures (e.g. standard deviation, lower partial moments) that adequately capture the volatility of this performance indicator. Following these decisions, the hedging efficiency (*HE*) can be used to quantify the relative reduction of the volatility of the performance indicator obtained by a particular risk management activity in a particular farm (OECD, 2000).

Various internal and external instruments can be used to reduce the risk in farming (Frentrup *et al*., n.d.; FAO, 2006; Offermann *et al*., 2017). On the one hand, after decades of increasing farm specialization, the diversification of the production program is again considered as a relevant tool for farm risk management (Augère-Granier, 2016; DESTATIS, 2020; Snorek *et al*., 2023). On the other, trading in commodity futures exchanges (CFEs) is seen by many economists and policymakers as a valuable risk mitigation tool for farmers (Veerman *et al*., 2016; Prager *et al*., 2020; DBV, 2021, p. 239). Farmers can use CFEs to fix their producer prices months or even years in advance of the production date, without the need for physical commodity exchange and without being exposed to counterparty risk as with bilateral forward contracts.

So far, the adoption of futures trading by German farmers is quite modest (Schaffnit-Chatterjee, 2010; Adämmer *et al*., 2014; Möllmann *et al*., 2018). Furthermore, some farmers who enter into futures contracts seem to use them as speculators hoping to make short-term profits, rather than as producers seeking to mitigate their long-term income fluctuations (Michels *et al*., 2019). In other words, they bet on negative price developments during the lifetime of the futures contract (Anastassiadis *et al*., 2014). The generally low uptake of trading in CFEs by farmers raises the question of whether it is as suitable a tool for mitigating whole-farm risk as many non-farmers seem to believe.

As early as 1848, the largest CFE for agricultural commodities, the Chicago Board of Trade ("CBOT"), was established (CFTC, 2023; CME Group, 2023). In contrast, CFEs for agricultural commodities in Europe were established only in the last quarter of the 20th century (USDA, 2004). A large, market-oriented part of the literature on CFEs focuses on its price-transparency function, price transmission, and the development of forward prices for agricultural commodities over time (Stevens, 1887; Hardy and Lyon, 1923; Morgan *et al*., 1994; Carter *et al*., 2011; World Bank, 2022; Miljkovic and Olson, 2023). Another, farm-oriented strain of the literature deals with the potential of CFEs to mitigate risk in farming. This includes the consideration of basis risk, which arises from fluctuating differences between futures prices and local spot prices (Graf, 1953; Pennings and Meulenberg, 1997; Bina *et al*., 2022).

Hedging in CFEs has generally attracted less attention in Europe, including Germany, compared to the US. This can be attributed both to the shorter history of CFEs in Europe and the EU price support system, which for a long time protected the mostly small family farms in Germany from volatile market prices (Pflugfelder, 1991). Prior to 2000, the literature by and large did not concern itself with futures trading by German farmers. But following the phasing out of the price support system after 2000, agricultural specialist journals started to recommend trading in CFEs as a suitable risk management tool for German farmers (Irps, 2007; Brüggemann, 2008; Steffin, 2008; Hares, 2009a, b; Stöver, 2016; Loy *et al*., 2017), without this being scientifically verified. Only a subset of the published articles in relevant journals explicitly addresses the fact that the effectiveness of hedging as a risk management instrument should be evaluated based on its ability to reduce risk at the whole-farm level (Hares, 2009b; Reinsch *et al*., 2011; Hirschauer *et al*., 2014a, b). This perspective is crucial for assessing the practical relevance of futures trading in agriculture but has not yet been sufficiently emphasized in the existing literature.

This is probably because the infant scientific literature on future trading in farming (cf. Mahul, 2003; Ziegelbäck and Breuer, 2010; Ziegelbaeck and Breuer, 2014; Zuppiroli and Giha, 2016; Bohl *et al*., 2017; Loy *et al*., 2017; Kellermann, 2018; Penone *et al*., 2021) has so far primarily focused on simplified farm models – often considering only a single producer price as a risk factor, rather than examining the impact of futures trading on the economic risk of the farm as a whole. Focusing exclusively on the price volatility of one product would only be adequate for farms that produce this single product in fixed quantities and at fixed costs (cf. Salhofer and Zoll, 2005).

In complex agricultural operations, rational risk management decisions must take into account the uncertainty of all output prices and quantities involved as well as the uncertainty of all input prices and quantities involved (Just and Rausser, 1981; Moschini and Hennessy, 2001; Doms *et al*., 2018). McKinnon (1967) was one of the first to go beyond the exclusive focus on output price volatility by considering the uncertainty of both output price and output quantity. However, the study still focused on the sales revenues from a single product and abstracted from the uncertainty in input prices and quantities. Other studies that jointly modelled the uncertainty of sales revenues followed (Rolfo, 1980; Anderson and Danthine, 1983; Lapan and Moschini, 1994; Moschini and Lapan, 1995).

Only a few studies on futures hedging adopted a whole-farm risk approach and considered that the risk reduction obtained by a risk management activity needs to be measured against the volatility of the economic performance of the whole farm. Turvey and Baker (1989, 1990) investigated the importance of hedging in different financial structures. They used a stochastic model in an expected utility approach to show that hedging activity is positively related to risk aversion and farm financing. Collins (1997) highlighted the innovative, holistic approach of these studies but also emphasized that individual (real farm) data are needed to provide farmers with practical decision-support. Motivated by the search for an economically meaningful lower-partial-moment risk measure, Erchinger *et al*. (2020) analyzed how diverse hedging strategies would change the probability and extent of falling below the break-even point. While looking at the break-even point – and thus profit – seems to represent a conceptual methodological advance towards a whole-farm risk perspective, the study's unrealistic model assumptions (with the wheat price as the only volatile factor) reduce the study back to an analysis of price volatility. In contrast, Neyhard *et al.* (2013) acknowledged the fact that the analysis of risk management activities must not be separated from the farm's financial and production structure. Consequently, they took a whole-farm risk approach and examined how futures and options trading in the dairy feed and commodity markets would affect a dairy farm's cash flow variability and thus its ability to service debt. But the study's informational value is limited as it is based on a single farm and simplified assumptions that abstract from real farm data.

Overall, the literature on the risk effects of futures hedging appears to lack whole-farm risk approaches, especially ones based on real-farm data. In the analysis of weather index insurance, in contrast, some studies adopted a whole-farm risk approach based on real-farm data. For instance, Urban (2019) analyzed the hedging efficiency of 20 German farms using different forms of weather index insurance over a 20-year time frame. Duden *et al.* (2019) further developed this methodological approach and expanded it to a larger sample of 377 farms from the German Farm Accountancy Data network ("Testbetriebsnetz") (BMEL, 2024; Thünen-Institut, 2024). To our knowledge, however, there are no studies that have systematically investigated the efficiency of futures contracts in mitigating whole-farm risk in a substantial number of real farms. The problem is that while farm models that abstract substantially from real-farm complexities can provide valuable first explorations on this topic, the effects of hedging found in such models have little external validity. As a result, little is known to date about the practical benefits of futures trading for farmers. We therefore conducted a small pilot study on the risk effects of hedging in a sample of 30 farms in Bavaria (cf. Sigl and Hirschauer, 2022). Contrary to expectations, hedging was associated with an increase of profit volatility in most of these farms. In view of these challenging findings, we now scrutinize the conventional wisdom in a large-scale study and investigate how futures trading would have affected the whole-farm risk of 2,197 German farms in the past. The farms under study are located in Bavaria and the new federal states and have different production orientations. Surprisingly, we found that hedging would have increased the variability of farmers income in most cases. This might trigger hedging analysis in other regions and farm types.

2. Methodological approach and data

2.1 Methodological approach

Our analysis is based on accounting data (financial statements) of 2,197 farms over a 21-year period (agricultural business years from July to June, for the period 2000/01 to 2019/20). We use the data in a historical simulation and assess how various hedging strategies would have influenced each farm's whole-farm risk. The methodology takes into account the brevity of the time series as well as potentially disruptive developments ("discontinuities"). That is, we deliberately refrain from estimating and predicting parametric distributions from the historical data. Instead, we content ourselves with answering the question of how the cash flows that would have been generated by futures contracts would have changed the income fluctuations of each individual farm, and of various types of farms, in the past. Our approach does not explicitly consider the individual risk management regimes (including futures trading) of the farms in the past. Due to data aggregation, we cannot identify whether individual farms utilized hedging as a risk management tool. However, given the low adoption of futures trading by farmers during the study period (Schaffnit-Chatterjee, 2010; Adämmer *et al.*, 2014; Möllmann *et al.*, 2018), our analysis, which models hedging as an incremental risk management tool, can be understood as approximating the effect of hedging for the farms under study. This provides a meaningful information base from which to derive promising avenues of future research and from which to make educated guesses as to whether and in which contexts hedging can reduce whole-farm risk in the future. Before carrying out the historical simulation, the following methodological steps are taken.

Specification of performance indicator: Accounting for the fact that the evaluation of risk management activities cannot be separated from the farm's production and financial structure, we adopt a whole-farm risk approach. More precisely, we use "adjusted profit" (*AP*) as a performance indicator, the fluctuations of which are assumed to be subject to risk mitigation. The *AP* is calculated by adjusting the farm profit from the financial statements for out-of-period income and expenses, and by deducting the opportunity cost of family labor based on the BMEL's standardized wage rates (BMEL, 2023a, p. 136):

$$\begin{aligned} AP = {} & \text{Farm profit according to financial statement} \\ & - \text{Income belonging to other periods} \\ & + \text{Expenses belonging to other periods} \\ & - \text{Opportunity costs for family labor} \end{aligned} \tag{1}$$

A farm's *AP* represents the ordinary earnings, obtained from its operating activities in a business year, that are available for net investments (farm growth) after the private withdrawals for the living of the farm family. These withdrawals are equated with the standardized opportunity costs for family labor. An *AP* of less than zero thus indicates a loss from ongoing operations and thus a loss of substance, unless capital is raised from external sources. The *AP* is normalized per hectare (ha) to facilitate comparisons between farms of different size.

Measurement of risk reduction and its costs: We use the *HE* in terms of the relative reduction of the standard deviation (*SD*) of the *AP* as main measure indicating the suitability of different hedging strategies for whole-farm risk mitigation. The *SD* is computed from the trend-adjusted time series of the *AP* of each farm [1]. In each year, we compute a fictitious AP_{hedged} by adding the profit or loss from the hedging transaction (including transaction costs) to the $AP_{unhedged}$. All hedging costs and profits are allocated to the accounting period on an accrual basis. The *HE* is determined for each farm through historical simulation ("what-if analysis") spanning from 2000/2001 to 2019/2020. The computation of the *HE* involves contrasting the *SD* of the annual $AP_{unhedged}$ in €/ha with the *SD* of the annual AP_{hedged} over the 21-year period of analysis:

$$HE = \frac{SD_{unhedged} - SD_{hedged}}{SD_{unhedged}} \tag{2}$$

A positive (negative) *HE* indicates a percentage reduction (increase) in the standard deviation of the trend-adjusted *AP*s that would have been caused by a given hedging strategy.

Taking into account that the distribution of the *AP* might be asymmetric, we complement the *HE*-analysis based on the *SD* with *HE*-analyses based on two downside-risk measures: shortfall risk (frequency of a negative *AP*) and average shortfall (average level of negative *AP*). In addition, we assess the costs of each strategy by comparing the 21-year average $\overline{AP}_{hedged}$ to the average $\overline{AP}_{unhedged}$ (after consideration of transaction costs). If a strategy causes a positive *HE* (i.e. a risk reduction) but an income loss on average ($\overline{AP}_{unhedged} - \overline{AP}_{hedged} > 0$), this loss is interpreted as "the costs of risk reduction."

Specification of hedging strategies: We analyze identical hedging strategies on all farms to ensure comparability across different locations and farm types. All examined hedging strategies are based on taking a short position on the wheat futures contracts "Milling Wheat No.2" (from Euronext Paris). We consistently chose futures contracts with the latest maturity within the calendar year because such contracts fully cover the entire hedging period and provide sufficient flexibility for closing the position. All strategies are based on the assumption that a long position is taken on July 15th of the respective harvesting year to close out the contract. Both for long and short positions we use the final daily settlement price. If Euronext was closed on the day of the planned execution, the price from the next trading day is selected.

Countless hedging strategies can be developed by varying other parameters such as the hedging volume and the time at which the contract is concluded. This study limits itself to examining the *HE* of nine distinct strategies (3×3) by differentiating three hedging volumes ("hedge ratios") and three hedging dates ("hedge durations"):

(1) Hedging volumes ("hedge ratios")

- Routine hedge = 50% of farm-specific average yield
- Full hedge = 100% of farm-specific average yield
- Levered hedge = 200% of farm-specific average yield

(2) Hedging dates ("hedge durations")

- Fixed-time hedge: short on October 15th
- Split-time hedge: short (1/3) on October 15th, January 15th and, April 15th
- Limit hedge: short (October 15th – July 15th) if futures price >195 €/ton

First, the strategies differ in the dimension "hedging volume." Take the "full hedge" (100%) as example. A full hedge means that the farmer enters into a short position for 100% of the expected wheat quantity in the respective year based on the acreage and the long-term average yield of wheat. The same rationale applies to the other two hedging volumes. The second dimension of a strategy is the hedging date. "Fixed-time" means that a short position is taken for the respectively specified volume on October 15th in the year before harvesting. In contrast, "split-time hedge" means that short positions are taken on October 15th, on January 15th and, on April 15th for one-third of the specified volume. Finally, "limit hedge" means that a short position is taken for the specified volume on the first day that a predefined minimum price on the CFE is exceeded, between October 15 and July 15. In this study, we chose a minimum price of 195 €/ton.

Derivation of farm types: To answer the question of whether there are farm types that show particularly low or high *HE*s, we form ex ante clusters based on key indicators that characterize the acreage, the financial and production structure, and the performance of the farms under study. In the cluster analysis (see section 3.2 for details), we identify four distinct farm types based on eight farm-specific characteristics: (1) acreage for farm size, (2) equity ratio for farm financing, (3) *AP* for farm performance, (4) average soil quality [2] for local production conditions, (5) crop revenue share and (6) aggregated crop + livestock revenue share for farm production orientation, and (7) wheat revenue share as well as (8) wheat acreage share as we analyze hedging based on wheat futures. To be more precise, instead of using averages, we consider the initial and final level of each indicator by computing their respective averages for the first three and the last three business years of the study period. We are thus able to consider the feature of temporal development in clustering.

K-means cluster analysis (in Python), following the algorithm of Lloyd (1982), is used for clustering the farms ("units") under study. The objective of this grouping approach is to reduce within-cluster variance, that is, to ensure that the observations for each characteristic ("indicator") in the same cluster are as similar as possible and, hand in hand with this, that the observation means ("centroids") of different clusters are as dissimilar as possible. A fundamental decision in cluster analysis concerns the number of clusters into which to group the units under study. While the decision depends on context and the investigator's subjective judgment without there being a clear decision rule, "cluster inertia" is widely used to help make the decision. Cluster inertia is based on the Total-Within-Cluster-Sum-of-Squares (TWSS). It describes the fact that the sum of the squared distances – across all characteristics and clusters – between the observations in a cluster (e.g. the acreages of the farms in the cluster) and the cluster centroid (e.g. the mean acreage in the cluster) decreases as the number of clusters increases. After visualizing cluster inertia through the "Elbow Plot KMeans" (see Appendix 1), we opted for a number of four clusters. This corresponds to the end point of the steepest drop of inertia before the curve flattens out when further increasing the number of clusters.

2.2 Data

2.2.1 Farms under study. We use a dataset containing the individual financial statements of approximately 3,600 farms in Bavaria and the new federal states between the agricultural business years 2000/01 and 2019/20. The financial statements conform to the accounting standards of the German Farm Accountancy Data Network (cf. BMEL, 2023b). Due to missing or implausible data, we excluded farms that did not meet the following pre-defined criteria: (1) minimum average wheat yield of 5 tons per hectare, (2) wheat cultivation in at least 17 out of the 21 years of the study period, (3) AP between -4.000 € and $+4.000$ € per hectare and year. Using these criteria resulted in a sample of 2,056 farms in Bavaria and 141 farms in the new federal states (see Figure 1). These farms exhibit widely differing acreages and production orientations.

In the fiscal year 2019/20, the 2,056 farms from Bavaria under study farmed around 165,000 hectares of farmland and the 141 farms from the new federal states around 31,000 hectares. The sample covers roughly 5% of the farmland in Bavaria and 1% of the farmland in the new federal states Destatis (2022). Table 1 describes key features of the farms under study.

In 2019/20, the farms under study farmed on average 89 hectares (thereunder 9 hectares of wheat) and they used 1.9 person-years of labor (including 1.6 person-years of family labor). The average farm profit amounted to 57,306 €/farm $\left(=\frac{1}{n}\sum_{i=1}^{n=2197} profit_i\right)$ or 641 €/ha $\left(=\frac{1}{n}\sum_{i=1}^{n=2197} \frac{profit_i}{acreage_i}\right)$. After factoring in extraordinary effects and the opportunity costs of family labor, the resulting average AP per farm amounted to $-3{,}712$ € $\left(=\frac{1}{n}\sum_{i=1}^{n=2197} AP_i\right)$ or -41 €/ha $\left(=\frac{1}{n}\sum_{i=1}^{n=2197} \frac{AP_i}{acreage_i}\right)$. Only 13% of farms showed a negative profit, but 61% of farms had a negative AP. With an average profit of 334 €/ha as opposed to 699 €/ha in Bavaria, the farms in the new federal states seem to perform worse than those in Bavaria. But farm profit does not yet take into account the value of family labor which represents the most important form of labor input in the mostly owner-run family farms in Bavaria (sole proprietorships). This

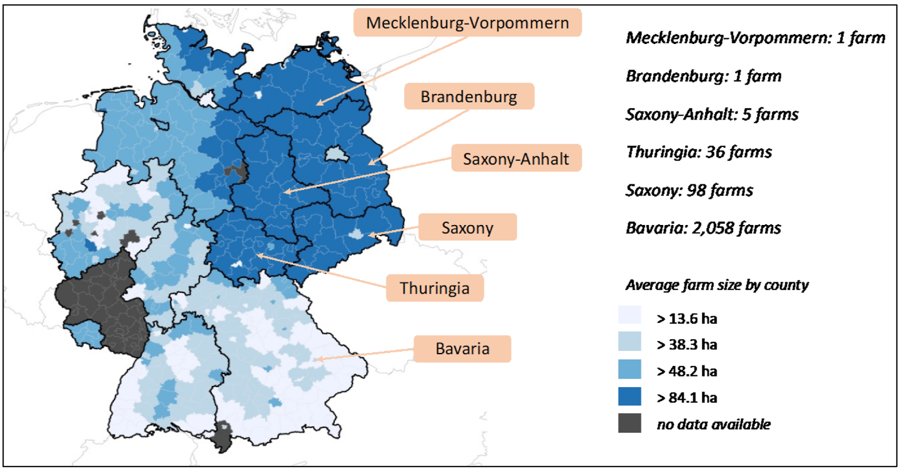


Figure 1. Location of the farms under study and average farm size in Germany by county in 2020. *Source*: Own representation based on map and data from Destatis (2023)

Table 1. Descriptive statistics based on the raw data of the farms under study in 2019/20 ($n = 2{,}197$)

		Location		Farm size		
	All farms	Bavaria	New federal states	Upper tercile	Middle tercile	Lower tercile
Number of farms	2,197	2,056	141	733	732	732
Average acreage in ha	89	80	222	162	68	37
Average wheat share	11%	11%	8%	9%	11%	16%
Average labor in person-years	1.9	1.8	3.2	2.6	1.8	1.3
Thereunder family labor	1.6	1.5	1.7	1.8	1.6	1.3
Average profit in €/farm $\left(\frac{1}{n}\sum_{i=1}^{n=2197} profit_i\right)$	57,306	56,118	74,569	91,034	52,514	28,324
Average farm-individual profit in €/ha $\left(\frac{1}{n}\sum_{i=1}^{n=2197}\frac{profit_i}{acreage_i}\right)$	641	699	334	559	768	762
Percentile for profit ≤0€	13	13	14	8	11	20
Average AP in €/farm $\left(\frac{1}{n}\sum_{i=1}^{n=2197} AP_i\right)$	−3,712	−4,387	6,210	15,689	−8,028	−18,826
Average farm-individual AP in €/ha $\left(\frac{1}{n}\sum_{i=1}^{n=2197}\frac{AP_i}{acreage_i}\right)$	−41	−54	27	96	−117	−506
Percentile for $AP \leq 0$€	61	61	58	44	61	77

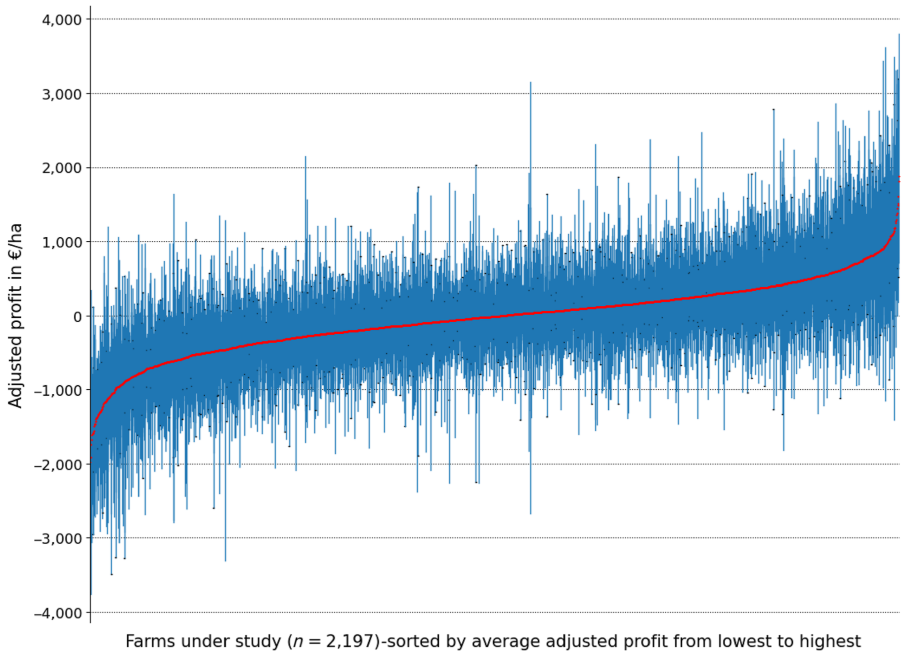
Source(s): Own calculations

is why farms in Bavaria actually perform worse after taking into account the opportunity costs of family labor in the amount of BMEL's standardized wage rates (BMEL, 2023a, p. 136). They have an average *AP* of −54 €/ha whereas the farms in the New Federal States, which are larger and often run as legal entities, realize an average *AP* of 27 €/ha.

Figure 2 displays the *AP*s of all 2,197 farms over the 21-year study period. The farms are sorted in ascending order according to their mean *AP*. To visualize not only the level of the individual performance but also its variability over time, each farm is represented by a whisker-plot.

Complementing the information on the *AP* and its spread in the individual farms, the bar chart in Figure 3 shows how many farms in the sample exhibited which shortfall frequency during the 21-year study period. Each bar represents the number of farms that suffered losses (in terms of negative *AP*s) in the specified number of years. A small share of less than 4% (100 out of the 2,197 farms) never fell short and achieved a positive *AP* in each year. On the other extreme, 175 farms (or nearly 8%) fell short in every single year and never achieved a positive *AP*.

As final descriptive statistic, we determined the skewness of the farm-specific, trend-adjusted *AP*s over the course of the 21-year study period. We provide the skewness information because the *SD* might not adequately inform decision-makers about their downside income risk if the *AP*s are asymmetrically distributed. In approximately 40% of the farms, the *AP*s are moderately skewed, with absolute skewness being between 0.5 and 1.0. In more than 10% of farms, the *AP*s are highly skewed, with absolute skewness being above 1.0. This result prompts us to complement the *SD*-based analysis of the hedging efficiency with an analysis based on shortfall frequency and average shortfall (see Section 3.3).



Key: *The red dots visualize each farms mean AP (in €/ha) and the "whiskers" (vertical blue lines) the range of the AP over the 21-year study period*

Figure 2. The level and the variability of adjusted profits (*AP*) across all farm (n = 2,197) over the 21-year study period. *Source:* Representation based on own calculations

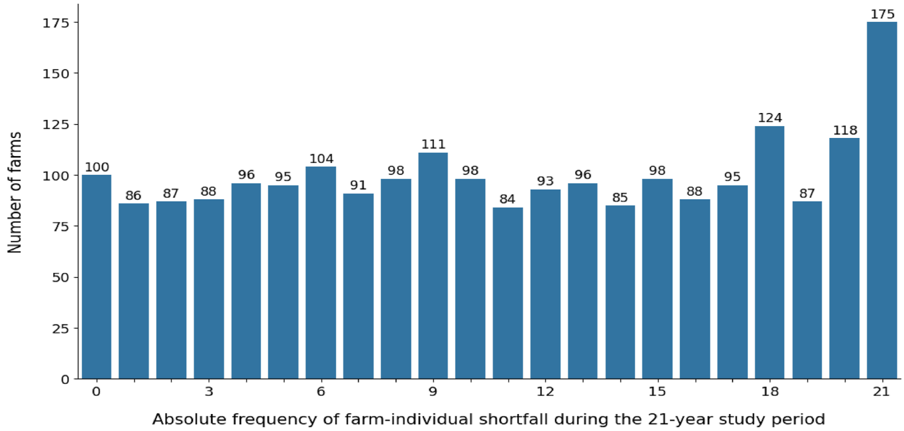


Figure 3. Occurrence of farm-individual shortfall frequencies ($n = 2{,}197$) over the 21-year study period.
Source: Representation based on own calculations

2.2.2 Data of futures prices. The daily prices of the relevant wheat futures contracts "Milling Wheat No.2" from Euronext Paris were obtained from EIKON (2022) database. The short futures contracts with the latest expiration dates of each year were used, and we assumed that a corresponding long position that closes out the contract is entered into on July 15th of the respective harvesting year. This means that a short contract that matures in Dec 2019, for example, is linked with a long position on July 15th 2019. The daily settlement prices for short and long positions were used. If the Euronext was closed on the date of the planned execution, the settlement prices of the next trading day were used.

Wheat futures contracts are traded as fixed units of 50 tons. For convenience, we assumed that portions of this quantity can also be hedged (as would be the case for producer groups, for example). The assumed transaction costs include the financing costs for the initial margin (4% per annum for 10% of the hedged amount) and the closing costs (60 € per contract or 1,20 € per ton of wheat). Any additional financing costs, for example for margin calls, were not taken into account due to their minor effect.

3. Findings

3.1 Impact of hedging on the volatility and level of farm profit across all farms under study

Using a box-whisker-plot to visualize the heterogeneity across farms, Figure 4 shows which hedging efficiency in terms of the percentage reduction in the *SD* of the annual *AP* (measured in €/ha; cf. eq. (2)) the nine hedging strategies would have caused across the 2,197 farms in the 21-year study period.

It is striking that hedging would have only marginally reduced profit volatility on average for the farms under study. The nine strategies caused a mean *HE* between 0% and 2%, with the median *HE* being always close to 0%. The median *HE* was lower than the mean *HE* for all strategies due to the predominance of positive outliers compared to negative ones. Increasing the hedge ratio – from "routine hedge" over "full hedge to "levered hedge" – amplifies the effects of hedging in both directions. The levered hedge, with its larger interquartile range, its longer whiskers, and its wider spread compared to the strategies with smaller hedge volumes, shows this most clearly.

We also checked whether the *HE*s were substantially different between farm sizes (upper, middle, and lower tercile) and regions (Bavaria as opposed to the new federal states). While the differences in the average *HE* were relatively small when comparing different farm sizes and regions (see Appendix 3 for more details), it is notable that the *HE*s varied more among the generally larger farms in the new federal states than in Bavaria (see Appendix 2 for more details).

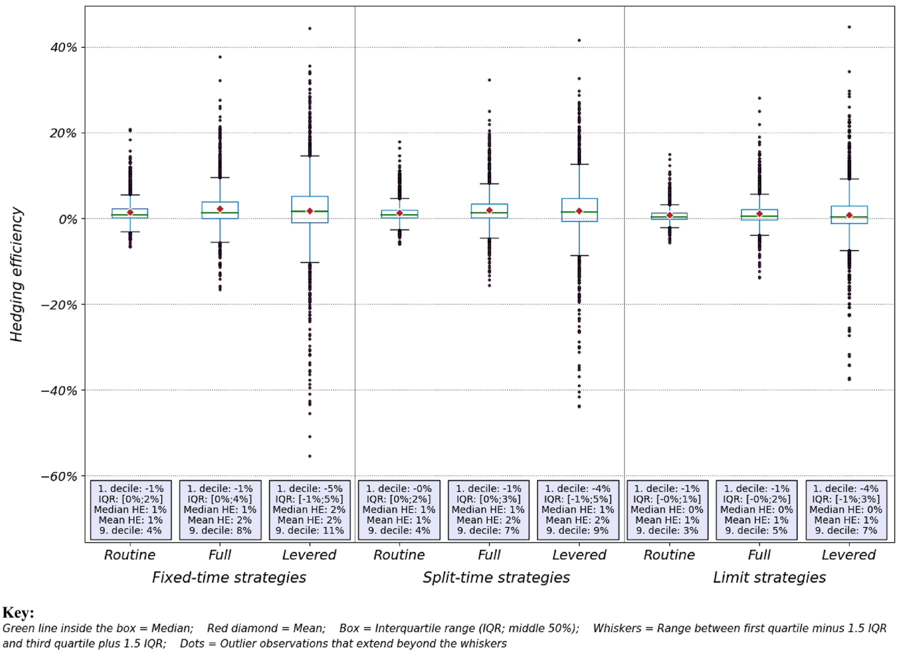


Figure 4. The hedging efficiency (*HE*) of all nine hedging strategies across all farms under study ($n = 2{,}197$).
Source: Representation based on own calculations

Besides *HE*, we also analyzed how hedging would have affected the level of farm profits. Table 2 shows that the fixed-time strategy and the split-time strategy would have resulted in losses on average, both in terms of the mean and the median of the farms' average over the study period. The limit strategy would have performed better with a slightly positive but quasi-break-even outcome. The predominantly negative income effect was primarily due to the costs associated with hedging. In order to generate a profit from hedging, the futures market would have to be outperformed, which was rarely the case. As increasing hedging volumes amplifies the income effect in both directions, considerable losses would have occurred especially for the levered hedge strategies (with a maximum loss of 91 € per ha).

Table 2. The impact of all nine hedging strategies on the level of adjusted profit(in €/ha and year)

	Fixed-time strategies			*Split-time strategies*			*Limit strategies*		
	Routine	*Full*	*Levered*	*Routine*	*Full*	*Levered*	*Routine*	*Full*	*Levered*
Mean	*−5*	*−11*	*−21*	*−5*	*−10*	*−19*	*1*	*1*	*2*
Standard deviation	3	6	13	3	6	11	1	2	4
Minimum	−23	−45	−91	−20	−40	−80	−4	−8	−15
Lower quartile	≤ −7	≤ −14	≤ −29	≤ −6	≤ −13	≤ −26	≤0	≤0	≤0
Median	*−5*	*−10*	*−19*	*−4*	*−9*	*−17*	*0*	*1*	*2*
Upper quartile	≥ −3	≥ −6	≥ −12	≥ −3	≥ −5	≥ −10	≥1	≥2	≥4
Maximum	2	5	9	0	1	1	9	17	35

Source(s): Representation based on own calculations

3.2 Heterogeneous effects of hedging in different farm types

To see whether hedging works differently in different farm types, we constructed four clusters following the approach described in Section 2.1. The clusters can be described as follows (see Table 3 for more information).

(1) The "*Specialized livestock farms*" (cluster 1) are characterized by a high proportion of crop + livestock revenue (98% on average), with a share of only 9% coming from crop production. With an average equity ratio of 93%, leverage is very moderate.

(2) The "*Specialized crop farms*" (cluster 2) also have a high proportion of crop + livestock revenue (94% on average), but they focus on crop farming, with crop revenue share amounting to 88% on average. With an average equity ratio of 96%, leverage is even lower than in cluster 1.

(3) The "*Leveraged-growth farms*" (cluster 3) are also characterized by a high proportion of crop + livestock revenue (97% on average) and, similar to cluster 1, their main revenue share is from livestock production (83% on average). But with a 75% increase in acreage and a 21% relative decrease in equity ratio, they had undergone considerable debt-financed growth. Compared to the other clusters, they exhibit the highest acreage (127 ha on average) and the lowest equity ratio (60% on average).

(4) The "*Atypical farms*" (cluster 4) have a comparable but somewhat lower equity ratio (86% on average) than clusters 1 and 2. Compared to all other clusters, they have a relatively low share of revenue from crop and livestock production (46% on average). During the study period, this share had decreased considerably (by 46% on average). This indicates that farms in cluster 4 have changed their business model in the direction of non-agricultural business alignments (e.g. energy production).

Table 3. The medians of the parameters used for clustering in the identified clusters (farm types)

	Cluster 1 Specialized livestock farms	Cluster 2 Specialized crop farms	Cluster 3 Leveraged growth farms	Cluster 4 Atypical farms
Acreage in ha [a]	59	55	134	70
Change of acreage [b]	*20%*	*2%*	*76%*	*9%*
Wheat revenue share [a]	2%	28%	4%	9%
Percentage change of wheat revenue share [b]	*0%*	*96%*	*0%*	*0%*
Crop revenue share [a]	9%	88%	15%	31%
Percentage change of crop revenue share [b]	*34%*	*78%*	*37%*	*−5%*
Crop + livestock revenue share [a]	98%	94%	97%	46%
Percentage change of crop + livestock revenue share [b]	*0%*	*−2%*	*0%*	*−46%*
Yield measure (cf. endnote 2) [a]	3,600	4,320	3,333	3,981
Change of yield measure [b]	*0%*	*0%*	*0%*	*0%*
Wheat acreage share [a]	18%	33%	18%	22%
Percentage change of wheat acreage share [b]	*10%*	*14%*	*4%*	*3%*
Equity ratio [a]	93%	96%	59%	86%
Percentage change of equity ratio [b]	*1%*	*1%*	*−22%*	*0%*
AP in €/ha [a]	−84	−366	−38	−153
Change of AP per ha [b]	*−22%*	*−4%*	*−56%*	*−53%*
Number of farms in cluster	1,190	481	386	140

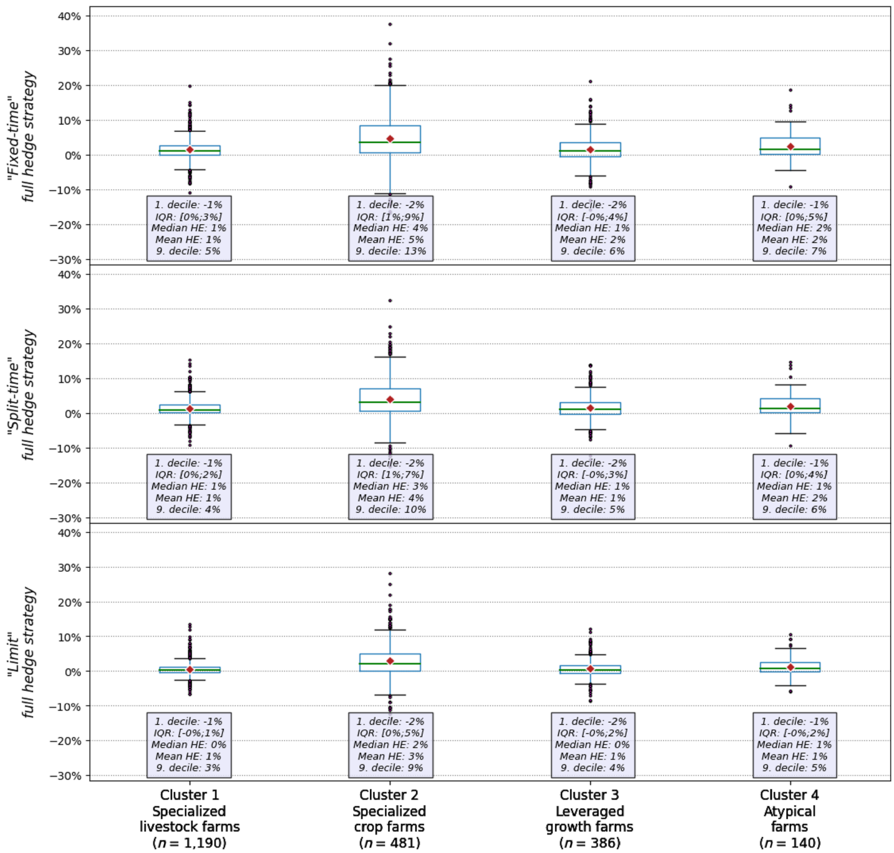
Note(s) [a]Mean of the last three years of the study period, [b]Percentage change compared to the mean of the first three years

Source(s): Representation based on own calculations

We chose the three full hedge strategies to illustrate the heterogeneous effects of hedging in different farm types. Similar results were found for the other hedge ratios (see Appendix 3 for more details). The comparison of Figures 4 and 5 shows that the results of hedging are very similar both for the different farm types and the aggregate of all farms: on average across farm types and strategies, hedging would have only marginally reduced income volatility. In addition, it would have reduced income levels (see Table 2). As regards differences, however, it is worth noting that the highest level and the greatest heterogeneity in *HE* was observed among the specialized crop farms, with mean *HE* ranging from 2% to 5%. In contrast, the average *HE* in the other farm types was close to 0%.

3.3 Impact of hedging on shortfall frequency and average shortfall

To determine the *HE* concerning the shortfall frequency, we first determined the frequency of shortfalls in each farm over the 21-year study period. Next, we measured the change in shortfall frequency. The results are shown in Table 4 [3]. A change in shortfall frequency of $+1$ means that farms would have suffered losses (in terms of a negative *AP*) in one additional year



Key: *Green line inside the box = Median; Red diamond = Mean; Box = Interquartile range (IQR; middle 50%); Whiskers = Range between first quartile minus 1.5 IQR and third quartile plus 1.5 IQR; Dots = Outlier observations that extend beyond the whiskers*

Figure 5. The hedging efficiency (*HE*) of the full hedge strategy in different types of farms (n = 2,197). *Source:* Representation based on own calculations

Table 4. Absolute change in shortfall frequency (no. of negative *AP*s) in the 21-year study period for all farms ($n = 2{,}197$)

	Fixed-time strategies			*Split-time strategies*			*Limit strategies*		
	Routine	*Full*	*Levered*	*Routine*	*Full*	*Levered*	*Routine*	*Full*	*Levered*
> +1	1%	2%	9%	1%	2%	7%	0%	0%	0%
+1	10%	16%	22%	9%	14%	21%	3%	6%	11%
0	83%	73%	58%	85%	75%	61%	92%	85%	77%
−1	6%	8%	10%	5%	9%	10%	5%	8%	11%
< -1	0%	1%	1%	0%	0%	1%	0%	1%	1%

Source(s): Representation based on own calculations

due to hedging. Accordingly, a change in shortfall frequency of –1 means that a negative *AP* would have occurred in one year less.

Over the 21-year study period, most farms experienced no change in shortfall frequency across the different hedging strategies. The proportion of farms in which the shortfall frequency changed by more than one year is negligible, with the exception of the levered fixed-time and split-time strategies, which caused shortfalls to increase by more than one year in 9% and 7% of farms, respectively. Depending on strategy, between 5% and 11% of farms achieved a reduction of the shortfall frequency by one year, but between 3% and 22% suffered an increase by one year.

Along with the small impact on shortfall frequency, the effect on average shortfall (average negative *AP* over all shortfall years) was, as expected, also rather small. On average across all farms, a slight decrease in the average shortfall would have been achieved by the fixed-time and split-time strategies, while a slight increase of average shortfall would have been inflicted by the limit strategy (see Table 5).

Finally, we can state that the impact of the hedging strategies on shortfall frequency and average shortfall increased as the hedge ratio increases, similar to the impact on the *AP* fluctuations.

4. Conclusions

The agricultural economics literature dealing with commodity futures hedging does not include many approaches that actually resort to a whole-farm risk approach. Many studies are based on simplified models that abstract from the interdependence of the many risk factors that jointly influence the economic performance of farms with a large number of interdependent inputs and outputs. A widespread, but apparently premature normative view associated with these models is that farmers are too unwilling to innovate and that they should more readily embrace futures hedging as an innovative risk management tool (section 1). Motivated by anecdotal evidence and an explorative study that challenged the established view, we use a large-scale historical simulation to study how various hedging strategies would have influenced the income fluctuations (“whole-farm risk”) in 2,197 German farms in the 21-year period from 2000/01 to 2019/2020.

Table 5. Change in average shortfall (average negative *AP* over all shortfall years) in € per hectare in the 21-year study period for all farms ($n = 2{,}197$)

	Fixed-time strategies			*Split-time strategies*			*Limit strategies*		
	Routine	*Full*	*Levered*	*Routine*	*Full*	*Levered*	*Routine*	*Full*	*Levered*
Mean	−3	−5	−11	−3	−5	−10	2	4	7
Standard deviation	21	41	82	18	36	73	15	30	61

Source(s): Representation based on own calculations

Based on the accountancy data of these farms, we measure annual farm income via the adjusted profit (*AP*). The *AP* factors in extraordinary effects and the necessary withdrawals for living expenses via the standardized living costs (opportunity cost) of unpaid family labor. A negative *AP* thus indicates a situation in which there are equity losses from the current business activities.

Contrary to popular belief, hedging would have only marginally reduced or even increased whole-farm risk in most cases and across different farm types and sizes. In addition, on average across farms, most hedging strategies would have reduced income levels due to hedging costs and/or losses in futures trading, with the exception of the "Limit strategy" which showed a nearly break-even outcome. In other words, farmers would often not have been able to "beat the market" and hedging would have led to perverse effects, as it would have caused costs, but would have increased the variability of farm income instead of the desired reduction of whole-farm risk. Our simulation study provides strong evidence that the general advice that farmers should use more commodity futures hedging to mitigate their income risk is misleading.

While our study analyzes a large number of real-world farm operations (2,197) across different regions of Germany, its informative value is initially limited by the specific sample, time period, and regional context under study. Although the sample is not randomly selected, the results are meaningful – particularly for Bavaria – due to the broad empirical base. The central inductive question is to what extent these findings can be generalized to other farms or settings. In this regard, our results – considered alongside the study's limitations – offer valuable indications for future research. Such work could further explore the potential and practical relevance of futures-based hedging as a tool for whole-farm risk management using still larger samples and data from other regions.

First, this study, as any other, could inevitably analyze only a limited number of potential hedging strategies. It must be recognized that other hedging strategies could lead to different results. Therefore, analyzing strategies based on different parameters (e.g. other hedging volumes or dates) and especially strategies based on other types of futures (e.g. grain, corn, rapeseed), up to complex hedging portfolios, and even other types of contracts such as options, could shed further light on the suitability and performance of hedging in agricultural risk management.

Second, there is the question of the impact of different contexts. Each farm and region possess unique structural characteristics that will impact the outcomes of hedging. While this study has shown that a general recommendation to increase the use of hedging in farm risk management cannot be seriously made, it remains to be seen whether there are particular types of farms or specific environmental and economic conditions where hedging could prove to be an efficient risk management tool that outperforms or can be usefully combined with alternative risk mitigation instruments.

Third, it must be noted that historical simulation is retrospective and that effects that would have occurred in the past if a particular strategy had been used do not automatically translate into valid predictions of future outcomes. This is particularly true in the case of disruptive events, such as climate change might be in certain regions, or Russia's war in Ukraine, as such discontinuities have the potential to substantially alter future trajectories. Nonetheless, it might be worth exploring the potential of established and modern prediction methods including time series analysis and machine learning for the evaluation of hedging strategies in individual farms. At this stage, we would use the results of this study to derive the educated guess (hypothesis) that the performance of futures hedging for the mitigation of whole-farm risk is limited, This might be due to the existence of other, more useful levers on farm level (e.g. diversification).

Last but not least, the heterogeneity of the results between farms emphasizes the fact that each farm and its decision environment is specific. Decision support for a particular farmer on whether or not to use a risk instrument, such as a particular hedging strategy, must therefore always be based on a farm-specific analysis of its cost and its benefits in terms of its potential to reduce whole-farm risk.

Appendix

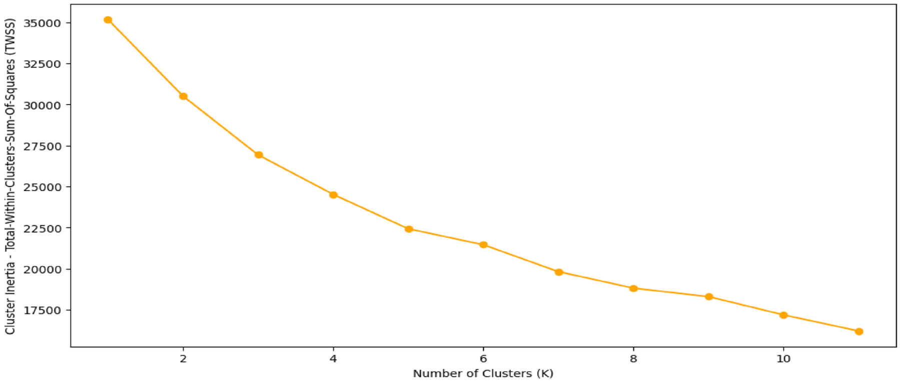
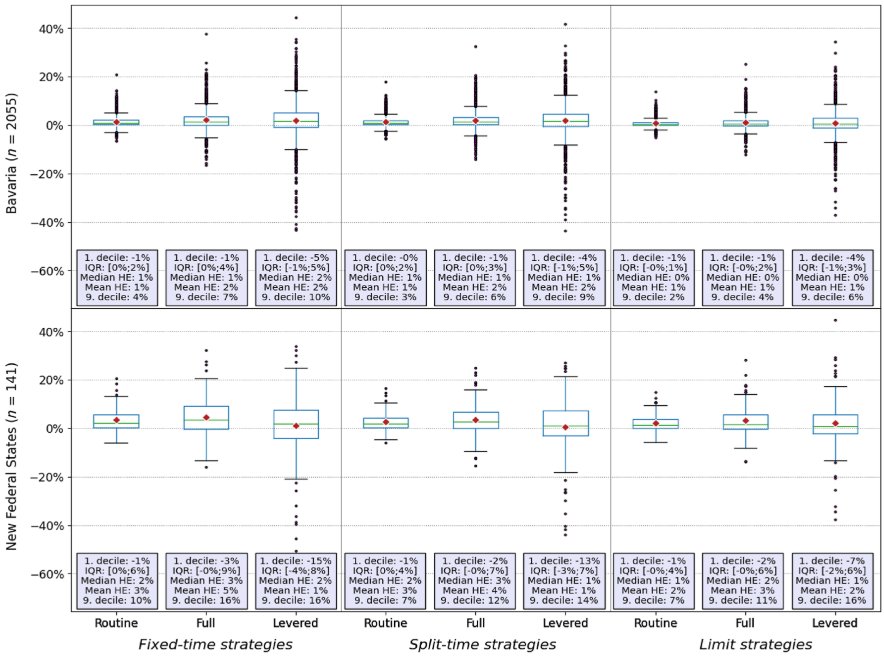
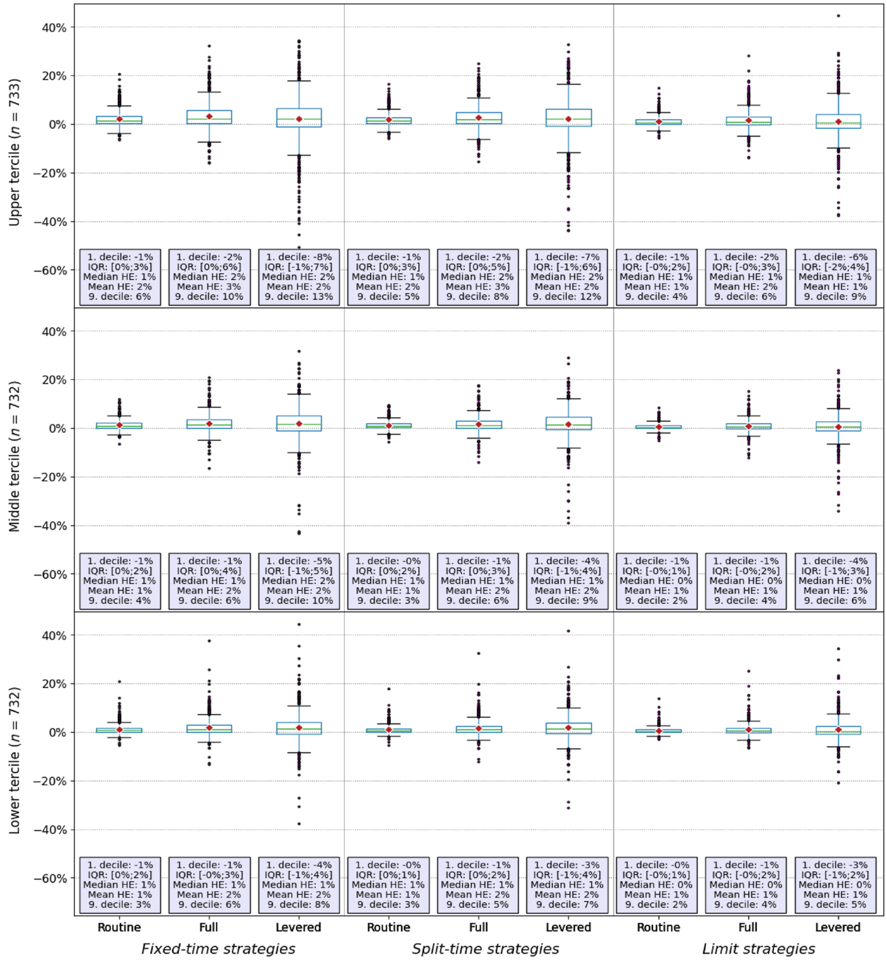


Figure A1. Elbow plot of KMeans cluster analysis. Source: Representation based on own calculation



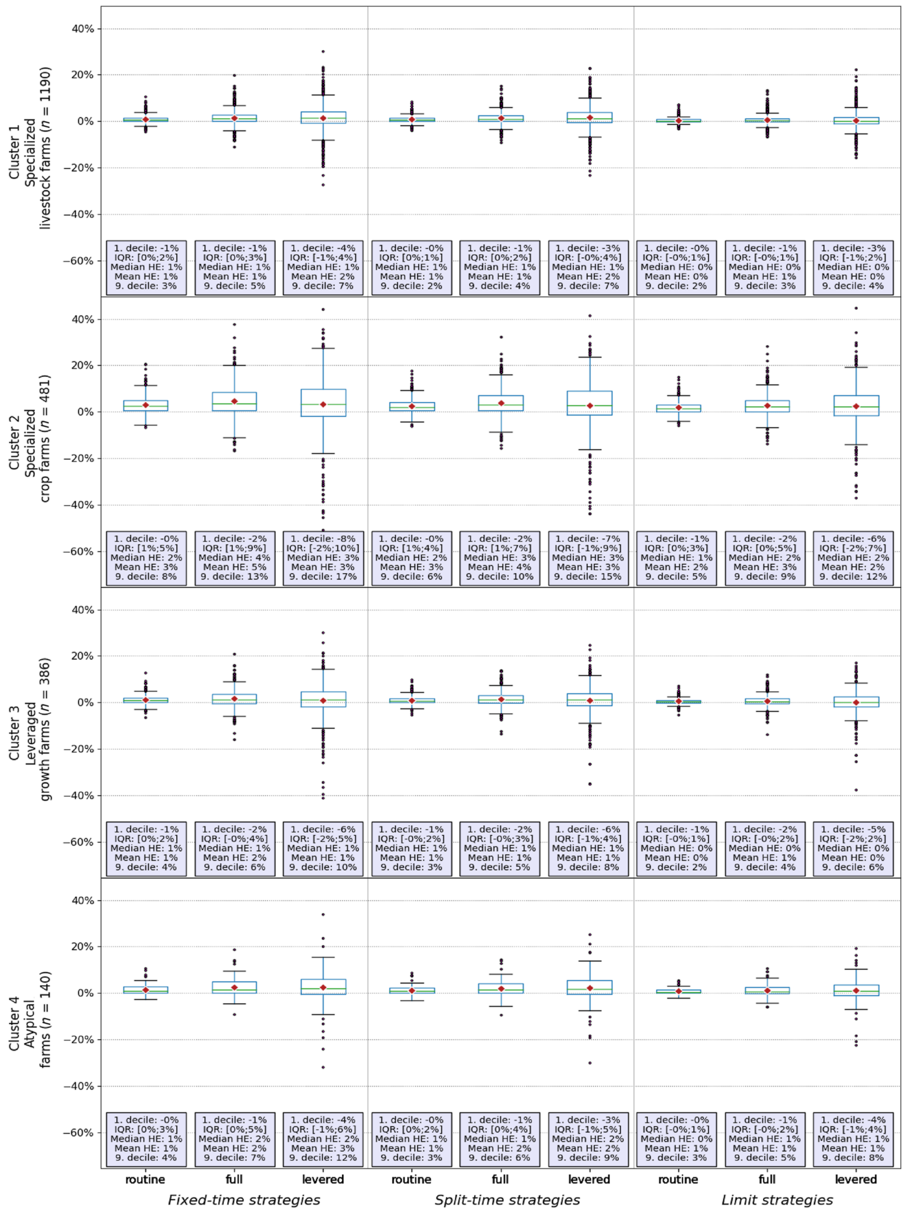
Key:
Green line inside the box = Median; Red diamond = Mean; Box = Interquartile range (IQR; middle 50%); Whiskers = Range between first quartile minus 1.5 IQR and third quartile plus 1.5 IQR; Dots = Outlier observations that extend beyond the whiskers

Figure A2. The hedging efficiency (*HE*) of all nine hedging strategies in Bavaria (n = 2,055) and the New Federal States (n = 141). *Source*: Representation based on own calculation



Key:
Green line inside the box = Median; Red diamond = Mean; Box = Interquartile range (IQR; middle 50%); Whiskers = Range between first quartile minus 1.5 IQR and third quartile plus 1.5 IQR; Dots = Outlier observations that extend beyond the whiskers

Figure A3. The hedging efficiency (*HE*) of all nine hedging strategies across different farm sizes (upper, middle, and lower tercile). *Source*: Representation based on own calculation



Key: *Green line inside the box = Median; Red diamond = Mean; Box = Interquartile range (IQR; middle 50%); Whiskers = Range between first quartile minus 1.5 IQR and third quartile plus 1.5 IQR; Dots = Outlier observations that extend beyond the whiskers*

Figure A4. The hedging efficiency (*HE*) in different types of farms (n = 2,197). *Source*: Representation based on own calculation

Notes

1. The "signal.detrend()" function from the "scipy" library in Python was used to eliminate linear trends from individual farm time series of the *AP*. Subsequently, we computed the individual trend-adjusted *SD* in €/ha for all farms.

   The farm-level trend adjustment was applied to account for individual developments and to ensure that structural differences in long-term income trends do not distort the analysis of the hedging effect. In addition, we also measured hedging efficiency without applying any trend adjustment – ultimately, this would have led to only marginally different results; therefore, we do not report the results based on the non-adjusted data separately.

2. We have used the German key figure "Ertragsmesszahl," which we have translated as "yield measure." It is a measure used in German agriculture to assess the quality of agricultural land. We normalized it per hectare to compare the soil quality in farms of different size.

3. To avoid misunderstandings, the following must be noted: in contrast to the *HE*, where *positive* values indicate a reduction of the *SD* and thus a risk management success (and vice versa), in the case of shortfall, it is *negative* values that indicate a reduction of shortfalls and thus a risk management success (and vice versa).

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